ELEMENTARY PHYSIOGRAPHY

R. A. GREGORY

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THE ELEMENTS

OF

HUMAN PHYSIOLOGY

FOR

SCIENCE STUDENTS AND MEDICAL STUDENTS OF THE FIRST YEAR.

BY

WALKER OVEREND,

B.A. (OXON.), B.SC. (LOND.),

Late Scholar of Balliol College and Radcliffe Travelling Fellow; Deputy Lecturer on Physiology at St. George's Hospital, London, W.

Profusely illustrated by Diagrams drawn and engraved from Original Sketches by the Author.

THE HOSPITAL says:—"As an elementary work on the subject of Animal Physiology, it is certainly wonderfully clear and well written; the arrangement of the various sections is excellent, and great pains have been taken with the illustrations. . . . Of this small book, as a whole, we have nothing but praise to bestow, and the author has produced a book which will be a great boon to students commencing Physiology, and although the subject matter is purely elementary in itself, yet the whole subject is put forward with that scientific accuracy and detail which is usually so conspicuously absent in elementary works of this kind. Again, another point in favour of the book is that the author has not endeavoured to popularise the subject of Physiology by writing in a popular strain, and so appealing to badly educated minds, but has maintained a high standard of technical precision throughout."

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ELEMENTARY PHYSIOGRAPHY.

New and Revised Edition.

ELEMENTARY

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PHYSIOGRAPHY.

BEING

A DESCRIPTION OF THE LAWS AND WONDERS OF NATURE.

BY

RICHARD A. GREGORY, 1864 -

Honours Medallist in Physiography; Author of 'Physical and Astronomical Geography,' &c.; Computer to the Solar Physics Committee, South Kensington; Fellow of the Royal Astronomical Society.

With numerous Original Illustrations.

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PREFACE.

THERE are so many books on Physiography, that, in order to justify the existence of this one, it is necessary to state in what respects it differs from those before it. In the first place, owing to the rapid advances of science in recent years, text-books which formerly ranked first of their kind have dropped out of date. The information they contained, though once constituting the standard of a good scientific education, is now almost matter of common knowledge. That this is the case is strikingly shown by the changes in the regulations of the Department of Science and Art, published in November, 1891. It has been resolved that—'After the May Examinations of 1892, the payment of £1 now made for the second class in the elementary stage of each science subject shall cease. An elementary paper will continue to be set in each subject, but the results will be recorded simply as *pass* or *fail*, the standard for passing being about the same as that now required for a first class, *i.e.*, about 60 per cent. of the marks obtainable.' The change is sufficient to necessitate a thorough revision of all the text-books that have been written to meet the requirements of the Examiners at South Kensington. The knowledge which it was once the aim of a teacher to impart to his students must now almost be regarded as the point from which to begin. To keep up with the march of science, teachers and students must now exercise themselves far more than was essential a few years ago. The time is coming—it has come—when an elementary knowledge of the facts and principles of science is considered requisite for the completion of an ordinary education. The mental horizon has been extended, so he who desires to see further into the workings of Nature has to climb to a higher level than formerly. It is on this account that the author has dealt more fully with many parts of his subject than is usual in an elementary text-book.

In recent years the fashion has grown to heap obloquy on books designed to meet the requirements of a syllabus. But there is some-*thing* to be said for such a course. The phenomena of nature are so *intimately* connected that examiners must state what they consider

to be the boundaries of their subject so as to guide the student's reading. The division is in many cases an arbitrary one, but it is essential. The science of Physiography especially needs its scope to be stated. Since the word was first coined there have been considerable differences of opinion as to its proper definition. Many teachers and authors of text-books suppose that Physiography is synonymous with Physical Geography. That this idea is not held by Professors Judd and Lockyer, the examiners in Physiography, is shown by the fact that since 1890 the questions in Physiography have been divided into two groups, one of them containing questions which relate principally to Physical Geography, and the other containing questions in the other part of the syllabus; students being required to answer questions in both groups. In fact, the earth is the centre of reasoning in Physical Geography, whilst Physiography embraces the whole of nature. The subject is thus very wide, but it is not deep. Physiography may indeed be regarded as a centre from which all the other sciences radiate. The student who desires to know more of the wondrous workings of nature must set out along the path he likes best. To some extent, therefore, Advanced Physiography is a misnomer, for as soon as the elements of the subject are left behind the domain of another science is trespassed upon.

In most text-books of Physiography the description of the earth as a part of the universe is relegated to a few pages at the end. The result is that this portion of the subject is generally scamped and very often not touched upon at all by the teacher. To remedy this, the descriptions of the movements of the earth and resulting phenomena have been inserted in early chapters in this book, and a larger amount of space than is usually deemed sufficient has been given to them.

At the end of each chapter will be found lists of questions set on the subject of the chapters at the May Examinations since 1877, additional questions being added where the Department questions were few in number. The author's experience is that there is no better method of testing a student's progress than by making him answer questions on the knowledge he is supposed to have gained.

The book is divided into twenty-one chapters, each of which roughly contains the subject-matter for one lesson. Teachers will, of course, omit any portions they think outside the range of Elementary Physiography, for the author has not confined himself strictly withi the bounds of the Departmental syllabus. The idea he has had

mind is that it is better to err by giving too complete information than by giving too little. The definitions at the heads of paragraphs ought to be learnt or thoroughly understood by the student, as they will furnish him a solid ground-work on which to build up his knowledge.

Those who have seen books through the press know to what a large extent an author is dependent upon his friends. Errors, typographical and otherwise, where passed unnoticed by an author, are often quickly detected by another reader. I am deeply indebted to several friends for the great assistance they have given me by reading through the proof sheets of this book. Mr. E. E. Fournier d'Albe, B.Sc., has kindly read through the whole of the book and furnished me with several excellent illustrations. This gentleman also prepared the nucleus of the introductory chapter. Mr. L. M. Jones, B.Sc., has been good enough to read the proofs and give me the benefit of his criticisms. Mr. S. H. Ford, A.R.S.M., has also aided me with a number of valuable suggestions and notes.

Many of the illustrations have been drawn especially for this book by my friend Mr. W. H. Harvey, B.A. Others have come from various sources. Messrs. Negretti and Zambra have furnished me with illustrations of the meteorological instruments for which they are famed, and Messrs. Wilson, of Aberdeen, have kindly given me permission to use some of their beautiful photographs. Illustrations from other sources are acknowledged in the course of the book.

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INTRODUCTION.

NATURE means the whole universe. To become acquainted with the world we live in and with the orbs in space, to understand the action of forces at work about us, to acquire a sure foothold for our every action and enterprise, it is necessary that we should become familiar with Nature's habits or laws.

A PHENOMENON is anything which we perceive either directly by means of our senses, or indirectly by an extension of our senses, through instruments or otherwise. The fall of a stone, the melting of ice, the burning of wood, are phenomena with which we are all familiar. All our knowledge of the laws of nature must be obtained through one or more of the five senses, sight, hearing, touch, taste and smell. It is quite possible that through disuse we have lost a sense, and therefore events may be taking place of which we can never have any knowledge as at present constituted, although they would appeal to the absent sense. For example, it is certain that vibrations of sound and light exist which can never be directly detected. Our senses are trustworthy enough, but the judgments to which we are led by actions upon them are often incorrect. Parallel lines can be so drawn that to the eye they appear curved; with the eyes shut it is impossible to tell in which direction a person snaps his fingers; lukewarm water appears hot to a hand taken out of cold water and cold to a hand from hot water; and these cases could be considerably multiplied.

SCIENCE is that department of mental activity which investigates the connection and correlation of natural phenomena. It is accurate knowledge obtained by observation and reasoning. The origin of science is lost in the remotest antiquity. The capacity for forming abstract ideas, which distinguishes man from the animal creation, is the first step towards a knowledge which not only remembers, but explains and predicts. But this power is not acquired in a day. It has taken the accumulated labours of centuries to bring a small tract of the unknown under the sway of the human intellect. From the beginning of time man must have been struck by the ever-changing

aspect of natural phenomena. But casual observations, excited by curiosity and sentimental admiration, do not constitute science. Yet such an elementary fact as 'fire burns wood' is in reality an inference from a long series of observations. Such facts, like isolated facts in history, are of little importance except in so far as they may help to explain other facts. After a mass of facts had been accumulated, their relation to each other could be studied, and the causes beneath them could be investigated, and then the foundation of science became possible.

EXPERIMENT consists in changing the conditions and arrangements of natural bodies in order to carefully examine their behaviour. It is generally known that iron is, bulk for bulk, heavier than water. Experiments have shown it to be seven times heavier. Water, when heated sufficiently, passes away into steam. By experimentally investigating the conditions, it has been found that this change of state occurs at a fixed temperature. Similar experiments are made with other liquids, and from the facts of observation certain conclusions are drawn. This method of observation and *induction* differs from that of *deduction*, in vogue before the time of Galileo. The latter begins by stating a cause or principle, as in the case of a proposition in mathematics, and then showing what effects follow upon it; the former observes the effects, and formulates a law which embraces them. After facts have been accumulated and inductions drawn from them, it is possible to deduce or prophesy what would occur if the conditions were repeated, and when these consequences have been verified by a large number of observations the statement of them is a *Law of Nature*. It is simply a convenient expression of a certain range of phenomena. The law can be changed, but it cannot be violated. If an experiment should be made which combats a law, then the law must be extended to include the new fact.

DIVISIONS OF SCIENCE.—Nature is so vast, and life is so short, that it is impossible for one man to carefully investigate the facts at present known. Scientists generally confine themselves to one department and make themselves masters of it. *Physics* or *Natural Philosophy* is the science which considers the phenomena of the material world. *Chemistry* is the science which treats of the changes of matter. *Astronomy* is occupied with the heavenly bodies, their constitutions, periods, and laws. *Geology* recounts the history of the earth. *Geography* describes the earth as it is. *Mineralogy* treats of the classification, characteristics, and properties of minerals. *Meteorology* is the science of the atmosphere. *Biology* investigates

the general conditions of organic life. *Botany* and *Zoology* describe the vegetable and animal organisms at present existing on our globe, while *Palæontology* studies the remains of beings which once inhabited it. But no hard and fast line can be drawn separating these sciences from one another. Many of the facts of astronomy can only be understood with a knowledge of physics and chemistry. Mineralogy must be connected with geology and with physics and chemistry. How, for instance, is it possible to separate mineralogy and chemistry when a chemical analysis of a mineral is often the only sure means of identifying it? Similarly, zoology and botany depend upon chemistry for an explanation of the reactions which go on in the tissues of organisms, and upon physics for other phenomena. In fact, all the sciences are joined together to form 'the solid ground of Nature.' The divisions are purely arbitrary, but are necessary for the development of fuller knowledge.

PHYSIOGRAPHY is the science of nature. It describes the chief facts and principles of the whole universe. All the sciences may be considered to radiate from physiography. Just as a tourist at cross-roads looks down one road after another until he selects that along which he will travel, so the student of physiography has placed before him a panorama of nature. He likes one picture better than the rest, and longs to get a deeper insight into it, and so develops into a devotee of science by following up his inclination.

In the present volume it is intended to give an outline of the results obtained, up to the present, in the sciences dealing with the properties, motions, and changes of material substances, in as far as they are not organised, or may be considered as inorganic. As there must be new words for new ideas, it has been found necessary in science to adopt some terms and expressions which are not familiar to every-day life. These are the 'technical terms,' without which it would be difficult to communicate knowledge with accuracy. It is hoped that in the following pages their explanation will be found clear and their use consistent. And if the bewildering variety of things seems to dissolve itself into order and harmony, the student will feel as if he had obtained a glance into the workshop of the world and seen the Master at work.

CONTENTS.

ELEMENTARY PHYSIOGRAPHY.

CHAPTER I.

MATTER AND MOTION.

Matter is the name of anything in the Universe that gives rise to phenomena which affect one or more of our senses.—On a clear night we see the heavens glittering with brilliant points of light which we call stars, but had mankind not been blessed with sight these objects would, as far as he was concerned, have no existence. We cannot see the air which surrounds us on all sides, but its presence is demonstrated to us, when the wind blows, through the sense of touch. The sense of smell may render us conscious of forms of matter which we can neither see nor feel, whilst the fact that the gas we burn in our houses may be felt as it issues from the burners, smelt as it escapes into the rooms, and utilised for illuminating purposes, gives us at once the idea that we are dealing with a material substance, body, or thing, by appealing to several of our senses.

The following are general properties or qualities possessed by all forms of matter:—

Matter is Impenetrable, that is, it occupies space, and therefore it is impossible for two portions of matter to be in the same place at the same time, or for a single portion of matter to occupy two places at the same time.

Matter is Porous.—A body is said to be porous when there are between the portions of matter of which it is composed, spaces not filled by them. Such substances as bread, sugar, cork, sponge, blotting paper, or the human skin, have sensible or visible spaces or pores between the particles of which they are composed, and are said to be *permeable*. Permeability is

the property utilized in filters, the pores between the particles of paper, sand, or carbon being large enough to let water pass, and small enough to prevent the passage of the solid matter in suspension. Substances such as steel, water, or air, show no apparent want of continuity even when microscopically examined; but since they may be compressed, and contract with cold, and since matter is impenetrable (see above), it is concluded that vacant spaces must exist between the particles. A direct proof of the porosity of steel is the fact that water can be forced through it by means of enormous pressure. The porosity of liquids is proved by mixing equal proportions of water and alcohol in a glass tube. The volume or space occupied by the two liquids when mixed is less than their total volume when separate, hence some of the particles of matter of which one is composed must have filled up the interspaces between the particles of the other.

An Atom is Indivisible and Indestructible.—The divisibility of a body means its capability of being divided up into a number of smaller parts; thus, a lump of salt can be crushed to fine powder. The division may be carried still further by dissolving a small portion of salt in a large quantity of distilled water. It is possible by this means to obtain water containing only $\frac{1}{80000000}$ of a grain of salt, yet this minute quantity can be detected by dipping a clean wire in the water, and holding it afterwards in the colourless flame of a spirit lamp, for the flame will be tinged with a characteristic yellow colour. A grain of gold may be beaten into a leaf having an area of 49 square inches, but so thin that 280,000 would only make up the thickness of an inch. And such leaves can be divided into fragments so small that one of them would only weigh $\frac{1}{5000000000}$ of a grain. But notwithstanding these minute portions into which a body may be divided, there is little doubt but that a limit must be reached beyond which further division is impossible. It is therefore assumed that all matter is made up of extremely minute and indivisible particles called *atoms*—a word which signifies that which cannot be divided. An atom is also well defined as something that cannot be cut in two.

Motion is change of Position.—The simplest kind of motion occurs when a change in the relative position or arrangement of bodies may be observed. Thus, a man travelling in a railway train has a *motion of translation* with reference to the telegraph posts apparently flying past him, but is at rest relativel

to the carriage he occupies. We shall see later on that the earth has a motion of rotation on its shortest diameter, or axis, and one of revolution round the sun, yet neither of these motions can be detected by observations of the arrangement of bodies upon its surface. The motions of the moon and planets are made apparent by their changes of position relative to the stars, but the standard of comparison is again not an absolute one, for none of the stars are at rest, and the whole of them may be in motion relatively to objects invisible to us. These examples are sufficient to show that one body may be in a state of rest with respect to another, but in motion with reference to some other body not moving with it—that, in fact, we can only know relative, and not absolute, rest or motion. And this is not all, for there is little doubt that although a body may appear in relative rest as a whole, yet the finest particles of which it is composed are in rapid motion among themselves, that is to say, the finest particles or *molecules* of which a lump of ice is built up are probably possessed of some kind of rapid motion, the magnitude of which is increased when the ice is transformed into water, and rendered still more violent when the water passes into the gaseous state. These motions, however, are too small and too rapid to be determined by direct observation, and are demonstrated by methods which will be alluded to in a future chapter.

In order to understand the laws concerning the motion of matter, it is necessary to define the standards or units of measurement.

English and French Units of Length.—The English *Unit of Length* is called a yard, and is the distance between two marks on a bronze bar deposited with the Board of Trade. A foot is one-third of this distance, and is the unit to which we shall generally refer.

The French do not use the same unit of length as is adopted in England, but one called a *metre*, which is slightly longer than a yard. When this length was agreed upon, it was supposed to be equal to one ten-millionth part of the distance from either pole to the equator of the earth, and a bar of platinum representing this length was deposited in the Archives of Paris. Later measurements have shown that the distance from either pole to the equator, measured on the circumference of the earth, is 10,000,880 metres, therefore the platinum bar is not the fraction it was supposed to be, but this does not of course affect its value as a unit. The metre is divided into ten parts called decimetres, each of

which is subdivided into ten parts called *centimetres*, each containing ten *millimetres*. The following table shows the relation that exists between the English and French or metric units:—

1 metre = 39·371 inches.	1 yard = 0·9144 metres.
„ = 3·281 feet.	1 foot = 0·3048 „
„ = 1·094 yards.	1 inch = 0·0254 „
„ = $1\frac{1}{11}$ yards.	„ = 25 millimetres (about).

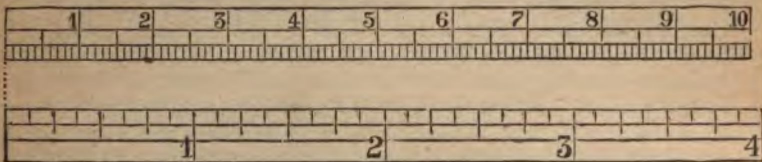


Fig. 1. Comparison of French centimetres with English inches.

Fig. 1 exemplifies the relation between these standards of linear measurement.

The Units of Superficial Area or Surface are easily derived from those of length, a square yard being equal to a square of which each side measures one yard, and a square metre being a similar square, having each side one metre in length. A simple calculation shows that one square yard = 0·8361 square metres.

The Units of Volume or Capacity should also be obtained from the units of length. The litre, or the volume occupied by one cubic decimetre, is the French unit of capacity. No simple relation exists between the English measures of capacity and length, one pint being equal to 34·659 cubic inches. One gallon is equal to 4·543 litres, and one litre is equal to 1·761 pints, or 0·220 of a gallon.

The *Unit of Time* or duration most frequently used in scientific work is the second, this being $\frac{1}{86400}$th part of the interval of time which we call a mean solar day.

Velocity is Rate of Motion.—A certain interval of time must elapse whilst a body passes from one position to another, that is, through a certain space. Velocity is, therefore, measured by reference to the fundamental ideas of *Space* and *Time*. In general, the unit of space used in England is the foot, and a second is the unit of time. Thus a body moving at the rate of one foot per second, or ten feet in ten seconds, has Unit Velocity, that

is, moves over the adopted unit of space in a unit interval of time. The velocity of a body is, therefore, determined by dividing the space traversed, by the time occupied. It is usual to speak of a ship as sailing at so many knots per hour, a knot being one geographical mile, that is, 2,029 yards, and to express the motion of a train in miles per hour or minute. Of course, in comparing the velocities of two bodies, the same units must be used for both.

Constant or Uniform Velocity is the Rate of Motion of a Body which passes over Equal Spaces in the Same Direction in Equal Intervals of Time.—If a ship sails at the rate of 12 knots per hour, and its velocity be constant, it will pass over 24 knots in 2 hours, 3 knots in a quarter-of-an-hour, and $\frac{1}{5}$ knot per minute. Hence, if constant velocity be known for any interval of time, the distance described in any other interval can be calculated. We could, therefore, say that a body is moving, or moved, at the rate of 60 miles per hour, although we did not observe its motion longer than a fraction of a second.

Variable Velocity is that of a Body which passes over Unequal Spaces in Equal Times.—A cannon ball leaves the mouth of a cannon with a certain velocity, and after a time comes to rest. During this interval the velocity of the ball must have been gradually decreasing, that is, the space it passed over in the first second was greater than that described in the next second, and so on, until it falls to the ground. Similarly, a stone let fall from a bridge gradually increases in velocity from the time it leaves the hand. At the end of the first second the velocity of the stone would be 32 feet per second, hence, if another body were given a velocity equal to that possessed by the stone at this instant, it would describe 32 feet in a second. The value of variable velocity is measured at any instant, by the distance which would be passed over in a unit of time by a body having the same velocity as that of the one in motion, at the instant under consideration.

The Average Velocity of a Body during any Interval of Time is the Uniform Velocity with which the same space may be described in the same time.—A familiar example of variable velocity is afforded by a railway train, which increases its rate of motion when commencing its journey, whilst a decrease of velocity occurs when a station is approached.

If a train be found to pass over 2 miles during the first 4 minutes of its motion, its *average velocity* is half-a-mile per minute. This *signifies* that another train travelling uniformly at the rate of

half-a-mile per minute for 4 minutes, would describe the same distance as a train moving from rest and travelling for 4 minutes with an average velocity of this amount. In the latter case the rate of motion would sometimes be greater and sometimes less than the average, and at one instant must have been equal to it.

To determine the average velocity of a body, the space traversed must be divided by the time occupied.

Velocity may change both in magnitude and direction. Thus, a ship may sail for one hour with a certain velocity relative to an observer, and the next hour may be moving faster or slower in a different direction. Had the original velocity continued, the ship would have found itself at a certain point after a certain interval of time. The straight line which joins this point to that really occupied by the ship represents the *change of velocity* in the interval.

Acceleration is Rate of Change of Velocity. It may denote an increase or decrease of motion, a change in direction, or changes both in magnitude and direction. —Acceleration, like velocity, may be uniform or variable. In the former case, the change of velocity that occurs in a unit of time, is a measure of the acceleration of the body under consideration.

If a stone be dropped from a bridge, at the end of the first second it will have a velocity of 32 feet per second. The same velocity will be added during the next second, so that at the end of this time the velocity of the stone will be 64 feet per second. In like manner, the velocity of the stone at the end of the third second will be 96 feet per second, and so on for any length of time. In fact, the rate of change of velocity of the stone, or any body falling freely, is 32 feet per second. *The acceleration due to gravity* is therefore said to be 32 feet per second per second. The repetition of the words 'per second' is intentional, and a little thought will convince the student that to speak only of an acceleration of so many feet per second is meaningless.

In ordinary language the word *acceleration* is only used to express the act of increasing velocity; a diminution of velocity being denoted by the word *retardation*, whilst a change in direction is termed a *deflection*. As will be seen by the foregoing definition, in physical science the meaning of the word 'acceleration' embraces retardation and deflection. So far, we have only considered uniform acceleration in the direction of motion. Uniform acceleration opposite to the direction of motion is exemplified when the velocity of a train is lessened by a constant

number of feet per second. A better example is afforded when a bullet is shot up into the air. In this case the bullet leaves the mouth of the gun with a velocity which is uniformly accelerated or neutralised by the action of gravity. An initial velocity of 1,280 feet per second would thus be destroyed at the rate of 32 feet per second every second, and so the bullet would come to rest after it had been in the air about 40 seconds.

It should be observed that acceleration is only a relative term and cannot be used in a true or absolute sense, for if everything in the visible universe experienced a simultaneous acceleration of the same quality, no means of observation could enable us to detect any difference in arrangement.

In the preceding pages we have considered the visible motions of portions of matter or material systems, and have referred to the invisible internal motions of the finest particles of which matter is composed. We have also shown that the idea of motion involves the fundamental ideas of space and time, whilst the laws laid down bring out the important fact that *a particle of matter can only occupy one position at any instant of time.* The results obtained may now be applied to a consideration of the action of *force* on material bodies.

Force is any cause that alters, or tends to alter, the motion of a body or that of its invisible particles.—A tintack will move towards a magnet placed near it, and finally stick to it. If, however, the tintack be held in the hand, near a magnet, a pull will be felt. This is an example of a force acting between two bodies although they are not in contact, and *tending* to produce motion. Such *impressed* or *external* forces, considered with reference to the alteration of the motion of bodies, are defined in Newton's axioms, or laws of motion, as follows:—

First Law of Motion. **Every body continues in a state of rest or of uniform motion in a straight line unless it is made to change that state by some external force.**—A block of wood soon comes to rest when thrown along the floor of a skating rink. This is due to the resistance of the air, and the friction set up between the wood and the comparatively uneven surface along which it travels, whereby the wood is acted upon by forces in the opposite direction to that of its motion. If these opposing forces be reduced by substituting an ivory block for the block of wood, and a horizontal sheet of ice for the skating rink, it is a matter of common knowledge that the block would travel further, that is, would not come to rest so soon. A ball

shot from a cannon will travel further still, because it has only the resistance of the surrounding air to overcome; but it ultimately comes to rest, no matter what velocity we can give it. If, however, the cannon could be transported into space, and the ball projected with any velocity, it would go on for ever in a straight line, unless some external force turned it out of that direction.

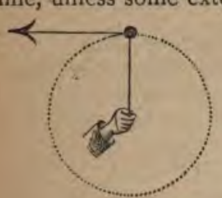


Fig. 2.
Movement of a body in a circular path.

All bodies that move in curves do so owing to the action of some force. If a stone be tied to a string, it can be swung round in a circle, but should the string break the stone will fly off along a tangent to the circle, and continue its motion in a straight line. (Fig. 2.) This law of motion brings out the primary property of matter, viz., its *inertia*.

Inertia is a negative property of matter, in virtue of which a body tends to maintain its state of rest or of uniform motion in a straight line.—When a lifeless body, such as a chair or table, is at rest, no one expects it to move without something moving it. All our experience tells us that matter cannot move of itself, or change the speed or direction of motion; some external force must act upon it. A man on a horse is thrown backwards if the horse give a bound forward; this is because the man's body tended to maintain its state of rest. If the horse should fall and so be suddenly stopped after being in motion, the rider is thrown over its head, because his body tends to maintain its state of motion. The jerks we receive when sitting in a railway carriage suddenly set in motion, or suddenly stopped, are also due to the inertia of our bodies. Again, a bicyclist on turning a sharp corner leans towards the corner, or he would be pitched over, for his body tends to continue moving in the original direction.

The mass of a body is the quantity of matter it contains.—The British standard, or unit of mass, is that of a piece of metal deposited in the Exchequer Office, and defined by Parliament to be the imperial pound. There should be a simple relation between units of volume and mass. Unfortunately, English weights and measures have not been adjusted on scientific principles, so no simple connection exists between them. It is well to remember, however, that a cubic foot of water

weighs very nearly 1,000 ounces when it is just above the temperature of freezing. The French unit of mass is the gram. It represents the weight of a cubic centimetre of water just above freezing point. A litre contains 1,000 cubic centimetres, hence the weight of a litre of water is 1,000 grams. This is a kilogram, and a piece of platinum representing this weight is kept in the Archives of Paris.

Momentum is quantity of motion.—'The numerical value of the momentum of a body is the product of the number of units of mass in the body into the number of units of velocity with which it is moving.' Hence, if a mass of 3 pounds has a velocity of 500 feet per second, its momentum is $3 \times 500 = 1,500$. A mass of 500 pounds, having a velocity of 3 feet per second, would also have a momentum $= 1,500$.

Impulse is the time-action of a force, and is equal to the whole momentum generated by it.—Impulse takes into account the *time* during which a force acts, as well as its *intensity*. In the words of Clerk Maxwell, 'The product of the time of action of a force into its intensity, if it is constant, or its mean intensity, if it is variable, is called the impulse of the force.'

When a blacksmith strikes an anvil with his hammer the anvil is given a certain momentum. If the force of the blow could be continued for a longer time, a greater quantity of motion, or momentum, would be generated. We can therefore say that the total effect of a force in communicating velocity to a body, that is, the whole momentum generated by a force, or the *impulse* of a force, is proportional to the force and the time during which it acts.

Second Law of Motion.—**Change of motion is proportional to the impressed force and takes place in the direction of that force.**—A corollary upon this law of motion is, that a body acted on by two forces will describe the diagonal of a parallelogram in the time in which it would describe the sides under the influence of the forces singly. Thus, if AB and AD in Fig. 3 represent, both in

Fig. 3. Parallelogram of Forces.

magnitude and direction, two forces acting on a particle at A, motion will take place in the direction AC, which, it will be seen, is the diagonal of the parallelogram ABCD. AC is called the *resultant force* of the two *components* AB and AD. As an example of this motion, consider two horses towing a barge; the barge does not move in the direction of either of the tow ropes, but up the river.

The truth of the second law is assumed in ordinary life in the same way as that of the first. Thus, the onward motion of a man in a railway carriage or a ship does not prevent him from walking from one side to the other. The engine exerts the force which carries the man forward, but this force does not interfere with that brought into action by his muscular exertions. Again, if a stone be dropped from the top of the mast of a ship in motion, the stone will fall at the foot of the mast notwithstanding the motion of the ship. This proves that the horizontal velocity of the stone, due to the ship's motion, does not interfere with the vertical pull that the earth exerts upon it. A simple modification of the experiment may be performed by letting any body fall in a moving railway carriage. Experience tells us that the body used will fall to the floor of the carriage, the circumstance of the train being in motion not affecting the earth's vertical pull at all.

In modern scientific language the word 'motion,' in the above definition, signifies *momentum*, and by an 'impressed force' is meant what has been defined as *impulse;* hence the statement of the second law of motion in terms of impulse and momentum is, 'the change of momentum of a body is numerically equal to the impulse which produces it, and is in the same direction.' In other words, whatever be the mass or motion of a body, the change of momentum produced by a given force acting for a given time is always the same. This is an important fact, because it enables us to compare different forces and masses.

Two bodies are of equal mass if equal forces applied to them produce, in equal times, equal changes of velocity.—Suppose a spring balance could be taken into space and used to push a body until the indicator of the balance pointed to a certain figure. The body would acquire a certain velocity, and if the same balance be applied to another body and the same pressure be exerted for the same time, and if the velocity acquired is the same in both cases, then we say that the two *bodies contain equal* quantities of matter, that is, they are equal *in mass.*

If the experiment could be performed we should find that 69 cubic inches of lead would acquire the same velocity as 100 cubic inches of iron when the same force was applied to both. We therefore say that the mass of 69 cubic inches of lead is equal to that of 100 cubic inches of iron.

The Unit of Force is that which acting on the unit of mass for the unit of time produces unit velocity.—Since change of momentum is proportional to the impulse, different forces applied to the *same* body for equal times produce different velocities. This may easily be understood if a spring balance be supposed to exert different pressures for equal times on any one body isolated in space. Thus, if a certain force acted on 69 cubic inches of lead for one second, and a force of twice the intensity was applied to 100 cubic inches of iron for the same time, then the iron would acquire twice the velocity of the lead.

The British unit of force is such that if it acted for one second on the mass of a pound it would produce a velocity of one foot per second. It is called a Poundal.

Newton's Law of Gravitation.—**Every particle in the universe attracts every other particle with a force whose direction is that of the line joining the two, and whose magnitude is proportional to the product of their masses divided by the square of the distance between them.**—This law is universally true. It holds good for the mutual attraction of the sun and earth, and for the mutual attraction between the earth and bodies upon it, the attraction in both cases being proportional to the masses of the bodies. It is a very common mistake to suppose that a body has weight as it has form or colour. *Weight is the pull of the attractive force of gravity*, and we measure it by the amount of force we have to use in order to overcome the earth's pull. The weight of a pound—that is, the force which causes it to fall—can be determined by letting it fall freely. If the experiment is made in Great Britain, the velocity of the pound at the end of 1 second will be about 32·2 feet per second. In consequence of the fact that the earth is not spherical in form, but an oblate spheroid, and that it is in rotation, the weight of a pound differs at different parts of the earth. At the Poles the same body would acquire a velocity of 32·25 feet per second after falling freely for 1 second, whilst at the Equator the value decreases to 32·09. A spring balance can be used to measure the force of gravity at different places on the earth. A substance

weighing 191 ounces on such a balance at the Equator would apparently weigh nearly 192 ounces if the experiment could be repeated at the Poles. An ordinary pair of scales, however, would show no difference at any point on the earth, because gravity would act in the same way on both the weights and the body being weighed. Such a balance only shows when the weights are equal.

The Intensity of Gravity is the same at the same place for all substances.—If two balls of the same size, one of lead and the other of cork, be dropped simultaneously from the same height, they will reach the ground at the same time. Certainly, the mutual attraction between the lead ball and the earth is 50 times greater than between the cork ball and the earth, but in the former case there is 50 times as much matter to set in motion, so that the quantity of motion, or momentum, generated in each case is the same. Newton suspended a number of pendulums of the same length, and found that they all vibrated in equal times, whatever were the materials of which the bobs were formed. This again proves that the attraction of the earth on any body is proportional to the mass of the body. In a vacuum all bodies, great and small, light and heavy, fall with equal rapidity, and were there no air surrounding our earth, and, therefore, no resistance to the motion of bodies, a feather would fall to the ground just as rapidly as a ton of lead. A handful of sand let fall would retain its shape as if it were compact stone, and a bucket of water would fall as a solid body, without separation into fine particles. An experimental illustration of the equality of the velocities given to two bodies by the force of gravity, is obtained by putting a bullet and a feather in a long glass tube, from which the air has been pumped, and letting them fall simultaneously. They both reach the bottom at the same instant. In like manner, a postage stamp placed flat upon a penny is protected from the resistance of the air, and will fall with the penny to the ground.

Third Law of Motion.—**Action and Reaction are equal and opposite, that is to say, the actions of two bodies upon each other are always equal and in opposite directions.**—The following are illustrations of this law:—(1) When a book rests on a table it exerts a downward pressure on the table in consequence of its weight, but the table exerts an equal upward pressure, and so prevents it from falling. (2) If anyone presses a stone with his finger, his finger is also pressed by the stone. (3) If a horse draws a stone fastened to a rope,

the horse is drawn backwards, so to speak, equally towards the stone. If this were not so either the horse would leave the stone or the stone would break away from the horse. (4) If one body impinges on another and changes the momentum of the other body, its own momentum experiences an equal change in the opposite direction. This case is that of the recoil of a gun when a projectile leaves it, the momentum of the gun being always equal to the momentum of the shot. We have, therefore, mass of gun $\times$ recoil $=$ mass of shot $\times$ velocity. Hence, if a gun weighing 20 lbs. discharge a shot weighing $\frac{1}{4}$ lb., with an initial velocity of 2,240 feet per second, the initial velocity of recoil of the gun is 28 feet per second in a direction opposite to that of the bullet.

The fact that a magnet attracts a piece of iron is a matter of common knowledge, and Newton's third law of motion tells us that the iron attracts the magnet with exactly the same force. This can be easily proved by balancing a rod of iron and a magnet together on a watch glass. (Fig. 4.) If the magnet attracted the iron with a greater force than the iron attracted the magnet, or *vice versâ*, the two bars would rotate until their motion was stopped, but as no such action occurs the two forces must be equal and opposite.

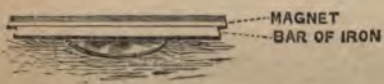


Fig. 4. Illustration of the law that action and re-action are equal and opposite.

Stress is the word used to denote the whole phenomena of the action, or the mutual action between two portions of matter.—The examples given above are sufficient to show that whether a pushing force or a pulling force be considered, both the portions of matter are affected—that there is no action without reaction. The word stress expresses the same as both these words, inasmuch as it considers the whole phenomena of the action. The third law of motion therefore shows us that all force is of the nature of stress. It should be evident from the illustrations given under this law, that the mutual action, or stress, between two portions of matter can always be regarded from two points of view. Each body produces or tends to produce motion in the other, hence each may be regarded as a force acting on the other, and action and reaction are different aspects of the same stress, the words themselves being interchangeable.

Tension and attraction are the words used to express a stress which tends to bring two portions of matter nearer together. Pressure and repulsion signify a stress in which the tendency is to separate two portions of matter.—A piece of stretched india-rubber connecting two bodies is an example of attractional stress. The two bodies tend to approach each other, whilst the two forces keeping them apart act in opposite directions. Let a weight be suspended by a thread or wire. If the weight is turned a stress of *torsion* is set up, the value of which increases with the angle through which the wire is twisted. But it is not essential that bodies should be visibly connected in order that a stress may be set up, for if a weight be held in the hand there is a stress of attraction between it and the earth. The force of gravity tends to make the weight fall, but the opposed action of the hand prevents it from doing so. There is a similar stress between the earth and the sun or moon, and between all portions of matter in the universe, whatever their size and whatever their relative distances may be. This is the gravitational stress, one of the results of which is the property of matter we call *weight*. A similar stress is that of cohesion, in virtue of which the particles of a lump of iron, stone, wood, &c., keep together. If this stress did not exist, everything would be reduced to fine powder. Later on in this book we shall consider the chemical stress, in virtue of which the atoms of a body have an attraction stress, called chemical affinity, for each other. But, besides these mutual actions between bodies and their component parts, which we may call permanent properties of matter, there are others that may be termed temporary. One of these is that, whereby a piece of iron when magnetised acquires the property of attracting iron. This is the magnetic stress to which we have previously referred. In the same manner a few substances such as sealing wax, amber, glass, are given properties of electrical attraction and repulsion, by rubbing them with flannel or silk, or a wire may be electrified so that it will attract iron filings. This is the electrical stress, but it disappears when the electrified body loses its electricity. These different states will be explained in future lessons. They are noted here in order that the student might recognise the important fact that all the so-called properties of matter are the result of stresses.

Work is the process by which stress produces change of motion.—We have shown that a stress exists between a stone *supported in the hand* and the ground, or between a piece of iron

and a magnet. If the stone be let fall the force of gravity does work upon it, or if the magnet draws the iron towards it the magnetic force does work, for in both cases changes of motion are produced by the respective stresses between the two portions of matter. The definition may be expressed in another way, viz., a force is said to do work when the body on which it acts moves in the direction of the force. The portion of matter moved is said to have *work done upon it.* A man who holds a mass of matter in his hand does no work so long as he supports it in one position. It is probable, however, that the hand does not remain in one position, but is pulled slightly down by the force of gravity, and then lifted up by muscular exertion. The amount of work done by a force is measured by the product obtained by multiplying the force by the distance through which the body moves in the direction of action. If a body is moved against the action of a force, the work done is measured in the same way. Thus, when a body is raised from the ground, work is done against the force of gravity. The unit of work generally used in England is the *foot-pound*, or the work required to raise a mass of 1 pound through 1 foot. If, therefore, a basket weighing 30 lbs. be raised through 20 feet, the number of units of work done against gravity is 30 $\times$ 20 or 600 foot-pounds.

Energy is the capacity of doing work.—The literal meaning of the word *energy* is the work that is in a thing. There are two kinds or forms of energy, viz., the energy which a body possesses in virtue of its motion, called *Kinetic Energy*, and that called *Potential Energy*, or, as it is sometimes termed *energy of position.* Clerk Maxwell remarks that the potential energy of a body is the power which it has of doing work depending on other circumstances than its motion. In other words, potential energy is that energy which is not kinetic. An example of kinetic energy is afforded by a moving cannon ball, a running stream, or a rotating fly-wheel. The raised weight or wound-up spring of a clock, or a waterfall, are examples of potential or stored energy; for the weight or spring have the power of doing work by turning the clock hands, and the energy of the waterfall may be used in many ways. The height to which the weight of a clock is raised, or the height of a waterfall, gives us the amount of energy which they possess. In like manner, the work done by a man in winding his watch is a measure of the potential energy possessed by the spring. Kinetic energy, or the work which a body can do in virtue of its motion, is equal to half the product of the momentum

of the body into its velocity. Thus, the kinetic energy possessed by a cannon ball weighing 200 lbs., and moving with a velocity of 800 feet per second, is $\frac{200 \times 800 \times 800}{2}$, that is 64,000,000 foot lbs. A magnet and a piece of iron, so long as they are separate, afford an instance of potential energy, for as they approach each other they may be made to bend a spring or do some other kind of work.

The principle of the Conservation of Energy asserts that the total quantity of energy in the universe is constant; that it may be transformed into any of the forms of which energy is susceptible, but cannot be increased or diminished.

A stone thrown up into the air affords an example of the transformation of energy from one form to another. When the stone leaves the hand it possesses kinetic energy, and as this is decreased it acquires potential energy. The motion of a clock pendulum is, perhaps, a better example. When the pendulum is started it has a certain amount of potential energy; but as it reaches the middle of its swing this diminishes and kinetic energy takes its place. In virtue of the kinetic energy, or energy of motion, the bob of the pendulum swings past the middle point, and is raised a little against the force of gravity. The kinetic energy is thus again transformed into potential energy. If all the original potential energy were transformed into kinetic energy the pendulum would continue to swing through equal distances to and fro for ever. But we know that a pendulum will not swing perpetually, and the reason is that a certain amount of energy is required to overcome the friction of the bearings, and that of the surrounding air. If we could isolate the pendulum and the air surrounding it, we should find that as it slackened down the bearings and the air would get very slightly warmer. We may imagine this heat being utilised to drive a small fan, and thus come to the important fact that heat is only a form of kinetic energy. When a drum is struck, part of the energy of the blow is transformed into heat, and part goes to produce the waves of sound. An electric current can be made to do work by driving a tramcar, in which case most of its energy is transformed into heat. It may also be used for illuminating purposes; hence, light is a form of energy. In fact, heat, sound, light, and current electricity are all forms of kinetic energy.

Energy and Heat.—Unburnt fuel possesses stored or potential energy in virtue of its power to combine with the oxygen in the

air and produce heat which may be transformed into mechanical work. Similarly, the gunpowder in a cannon possesses potential energy, and when it is exploded it imparts kinetic energy to the cannon ball. As the ball passes through the air its velocity is reduced because the kinetic energy is being expended in overcoming the resistance of the air, and thus producing heat energy. Similarly, when the target is struck it is made hot where the shot strikes it, because the remaining kinetic energy is converted into that form of energy which we call heat. But it does not matter whether the ball is stopped suddenly by an iron target, or slowly by impact against sand or water or any other substance. In all cases the energy of the visible motion is converted into heat.

A button rubbed against a piece of wood or on a coat sleeve becomes very hot, the reason again being the conversion of kinetic energy into heat energy. In a like manner the energy of a moving hammer heats a coin or any piece of metal upon which it falls. Researches made by the late Dr. Joule and others show that a definite relation exists between that energy which we call kinetic and that which we call heat. If some water held in a vessel be dropped from a definite height, and if the velocity which it attains be suddenly arrested, the kinetic energy is transformed into heat energy, and the temperature of the water is raised by an amount which is always the same under the same conditions. The kinetic energy which, when transformed into heat energy, raises the temperature of a given quantity of water, is therefore called the mechanical equivalent of the heat developed.

Sufficient has now been said to prove the principle of the conservation of energy. Like matter, energy can neither be created nor destroyed, but only changed from one form to another.

QUESTIONS ON CHAPTER I.

1. Describe the general properties of matter. Give proofs of the porosity of a solid of which the pores are invisible, and of a liquid and a gas.

2. What are the English and Metric units of length and area? How many centimetres are there in 30 metres and how many metres in 11 yards?

3. Define Motion, Velocity, and Acceleration. What is the average velocity of a body which moves over 16 feet in the first second, 32 in the next, and 64 in the third second?

4. A stone is thrown up into the air with a velocity of 96 feet per second. How long before it will come to rest? (Acceleration due to gravity = 32 feet per second per second.)

5. Define Force and Inertia, and give some examples of Newton's first law of motion.

6. Define Mass and Momentum. Masses of 5, 12, 30 lbs. are moving with velocities of 24, 10, and 4 feet per second respectively. What is the momentum of each?

7. What is the second law of motion? Give examples in illustration of its truth.

8. Equal forces act on two bodies for the same time and produce in them velocities of 300 and 200 feet per second respectively. What are the comparative masses of the bodies?

9. State the Law of Gravitation. Why does a lb. suspended by a spring balance appear to increase in weight when carried from the equator to the poles? Would any difference be observed if an ordinary balance were employed?

10. What is the third law of motion? Give some illustrations of it and show its relation to stress.

11. Name as many stresses as you can, and give an example of each.

12. Define work. How much work is done against gravity by a man weighing 140 lbs. climbing a hill 1,000 feet high? How much work is done by the same man in walking 10 miles along a level road?

13. What is meant by the conservation of energy? Illustrate your answer by some examples.

14. How does the motion of a pendulum illustrate the transformation of energy?

15. Give some examples of the conversion of kinetic and potential energy into heat, and of heat into kinetic energy.

16. A shell weighing 32 lbs., and having a velocity of 500, burst into two fragments, weighing 12 lbs. and 20 lbs. respectively. The velocity of the former was 700. What was the velocity of the latter?

17. In the case of a shot fired at a target state (*a*) why the velocity of the shot changes; and (*b*) why the target is made hot where the shot strikes it. (1890.)

18. Define stress, impulse, momentum. (1889.)

19. Define energy and stress. (1888.)

20. Define force, energy, momentum, stress. (1892.)

CHAPTER II.

PHYSICAL PROPERTIES OF MATTER.

MATTER can be considered as existing in three different states or forms, as solids, liquids, and gases. We are acquainted with many substances which are capable of appearing in each of the three states. Thus, ice is a solid which is converted into a liquid (water) by the action of heat, and then into a gas or vapour (steam). But the conversion of a solid into a liquid and a gas does not affect its weight, for a pound of ice would make a pound of water or a pound of steam. It is also possible to condense the steam back into water and ice, and so to prove that no alteration in chemical constitution takes place. We shall now investigate some of the physical properties peculiar to the different states of matter, and the causes producing them.

Cohesion is a property of matter which results from a stress of attraction between the various molecules of the same substance.—We have remarked that the gravitational stress exists between all particles in the universe, whatever the distance between them, and whatever their constitution. The cohesion stress may be considered as acting mainly when particles of the same substance are very near together; for example, between the particles of a lump of iron and a glass of water. If this stress ceased to act, everything would fall into extremely fine powder. It is stronger in some solids than in others, is considerably diminished when a solid is melted into a liquid, and practically ceases to act when the liquid is boiled away into vapour. The cohesion stress, therefore, tends to prevent the separation of the particles of a body, but its strength may be neutralised by the action of heat.

We will now give the general properties possessed by solids, liquids, and gases respectively, in consequence of cohesion stresses between the molecules.

Strain is the temporary alteration which is produced in the shape of a solid body by the action of a stress.—If a wire or a piece of india-rubber cord be stretched by a weight, the amount of stress called into action is represented by

the weight, whilst the stretch of the wire is a measure of the strain. When a beam is bent the particles on the under side are compressed and those on the upper side are extended. Here also the amount of compression or extension is a measure of the strain. Again, the angle through which a wire is twisted is a measure of a strain produced by a torsional stress. In fact, any distortion produced by a stress is called a strain.

Elasticity is the property of exerting stress when strained.—If a piece of wire be stretched, the molecules of which it is composed tend to recover their original position, and this internal force or stress is called elasticity. When the internal force is great, a body is said to be very elastic, but if there is only a slight tendency to recover the original form, a body is inelastic. A perfectly elastic substance is one that returns to its original shape when the distorting force is removed, but as a matter of fact, no solid fully satisfies this condition. Steel, quartz, and glass are very elastic substances; putty, mahogany and thread are comparatively inelastic. Liquids and gases are perfectly elastic.

When a rod is stretched lengthways by a force, the elongation produced is proportional to the force, that is to say, twice the force would produce twice the effect and so on. If, however, the stress produced by the stretching weight is increased beyond a certain limit, the strain or distortion of the body is no longer proportional to the stress, and when the stress is removed the body remains permanently distorted and does not return to its original shape and volume. Under these circumstances, we say that the *limit of perfect elasticity* has been passed.

The Tenacity of a substance is the greatest longitudinal stress which it can bear without breaking asunder.—The weight which just breaks a rod or wire of any substance is a measure of its tenacity. Within certain limits this breaking weight is proportional to the cross section of the rod or wire under experiment, hence in order to compare the tenacities of different substances, they should each have the same sectional area. Steel is very tenacious. Thus, a steel rod or wire which would carry 120 lbs. need only be of the same thickness as a rod of copper which would only carry 20 lbs., whilst wires of glass and lead of the same size could only bear weights of 3 lbs. and 1 lb.

***Ductility* denotes that property of bodies in virtue of which they permanently change their form under**

the action of stretching force.—Gold, platinum, and silver, are ductile substances, that is, are capable of being stretched out into fine threads. Quartz and glass are also very ductile when melted.

Malleability denotes that property of bodies in virtue of which they may be hammered into thin sheets.—The most malleable metal is gold, for this metal can be beaten out into sheets only $\frac{1}{280000}$ of an inch thick. Silver, lead, copper, platinum, and iron, may also be reduced to fine sheets, but none of these substances are nearly so malleable as gold. Brittleness is the opposite property to malleability, and denotes the liability to be fractured by a sudden blow. Ordinary glass is very brittle, so are cast iron, steel and sealing wax.

Hardness is that property of bodies in virtue of which they resist being scratched by others.—Toughness and rigidity are not necessarily accompanied by hardness, thus, wood is tough and rigid without being hard. The hardness of a substance is determined by finding out what substances it will scratch, and what substances will scratch it. Diamond will scratch every substance and cannot be scratched by any, hence it is the hardest known substance. The following table contains bodies so arranged that they may be scratched by the substances before them on the list, and can scratch anything arranged after them.

1. Diamond.
2. Corundum (sapphire, ruby).
3. Quartz.
4. Glass.
5. Steel.
6. Iron.
7. Copper.
8. Lead.

Viscosity denotes an imperfect state of fluidity.—Some substances pass very slowly from the solid to the liquid state. Thus, when glass and sealing wax are heated they become gradually softer, and finally reach an imperfect condition of fluidity. A body in such a state is said to be viscous. Treacle, honey, and tar are viscous substances, but must be classified as fluids, because they obey the law of, in time, setting themselves with horizontal surfaces. Mobility is an opposite property to viscosity, and a body possessing it more nearly fulfils the conditions of a perfect fluid. Alcohol and ether are more mobile than water, and water is more mobile than treacle. The force of cohesion between the molecules of a solid is greater than between the molecules of a viscous liquid, and is greater in a viscous liquid than in a mobile one.

The Density of a body is the mass of a unit volume.—If we compared a cubic foot of iron with a cubic foot of wood or water we should find that the iron had the greatest mass, and should speak of it as being the densest body of the three. Similarly mercury is denser than iron, and water is denser than air. The mass of a cubic foot of water is about 1,000 ounces, or $62\frac{1}{2}$ lbs., this, therefore, is the density of water. The density of mercury is 812, of iron 432, and of oak 73. When a gas is compressed, the molecules of which it is composed are packed more closely together, that is, the density of the gas is increased. If the pressure on the gas be doubled, the density is doubled, in fact the density in this case is always proportional to the pressure.

The Specific Gravity of any body is the weight of any volume of that body divided by the weight of an equal volume of water.—Six cubic feet of iron weigh 2,592 lbs., six cubic feet of water weigh 375 lbs., hence the specific gravity of iron is equal to $\frac{2592}{375}$ or 6·9. Similarly platinum is 22 times as heavy as an equal volume of water, whilst cork and alcohol are respectively about $\frac{1}{5}$ and $\frac{4}{5}$ as light as water.

The specific gravity of a solid may be determined through the hydrostatic principle that when a body is immersed in a liquid, it is borne up with a pressure equal to the weight of the liquid displaced (Fig. 5). Thus, if a lump of lead weighing 6 lbs. in

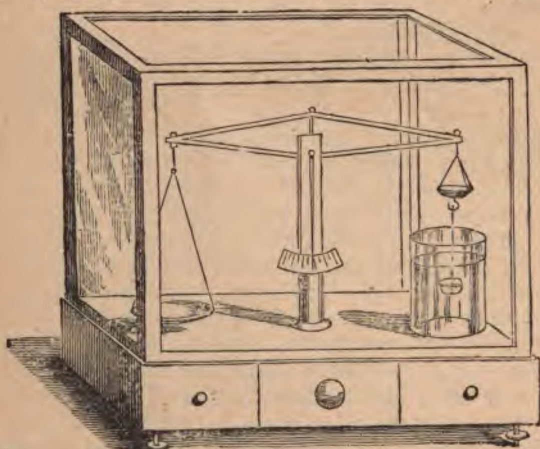


Fig. 5. Method of determining the specific gravity of a solid.

air be immersed in water, it will appear only to weigh about $5\frac{1}{2}$ lbs. because it is pressed up by the water with a force equal to the weight of $\frac{1}{2}$ lb. The weight of a lump of water of the same size as the lump of lead is therefore $\frac{1}{2}$ lb. and since

$$\text{specific gravity} = \frac{\text{weight of substance}}{\text{weight of an equal volume of water}}$$

we have specific gravity of lead $= 6 \div \frac{1}{2} = 12$ (nearly).

Wax has nearly the same specific gravity as water, and by means of a few tin tacks may be made to remain in any position because the upthrust is equal to the downward pull of gravity.

The specific gravity of a fluid may be determined by weighing a quantity of the fluid in a bottle, and then weighing an equal bulk of water at the same temperature. (Fig. 6.) A glass flask weighing $\frac{1}{2}$ lb. when empty, was found to weigh $2\frac{1}{2}$ lbs. when filled with water, and $2\frac{1}{4}$ lbs. when filled with olive oil. The weights of equal bulks of olive oil and water are therefore as $(2\frac{1}{4} - \frac{1}{2})$ is to $(2\frac{1}{2} - \frac{1}{2})$ that is, as $1\frac{3}{4}$ is to 2. The specific gravity of olive oil is therefore $1\frac{3}{4} \div 2 = \frac{7}{8}$ or 0·87.

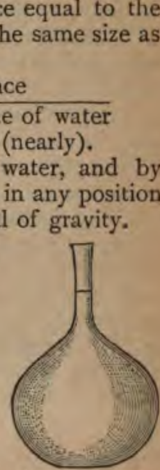


Fig. 6. Specific gravity bottle.

The following table contains the specific gravities of a few solids and liquids:—

Platinum ...	21·5	Mercury	13·60
Gold	19·3	Sulphuric Acid (Oil of Vitriol) ...	1·84
Lead	11·4	Chloroform	1·52
Silver	10·6	Human Blood ...	1·05
Copper	8·9	Sea-water	1·03
Tin	7·3	Linseed Oil	0·94
Diamond ...	3·5	Olive Oil	0·91
Brick	2·1	Oil of Turpentine...	0·87
Clay	1·9	Alcohol	0·79
Ice	0·9	Ether	0·71
Cork	0·24		

Since the weight of a cubic foot of water is 62·4 lbs. the weight of a cubic foot of any substance, that is, its density, is equal to 62·4 multiplied by its specific gravity. Thus the weight of a cubic foot of silver is $10·6 \times 62·4 = 661·44$ lbs. whilst a cubic foot of ice only weighs $0·9 \times 62·4 = 56·16$ lbs.

The weight of a gallon of water is 10 lbs., hence the weight of *a gallon* of any liquid is equal to 10 multiplied by its specific

gravity. A gallon of oil of vitriol therefore weighs $10 \times 1{\cdot}84$ or $18{\cdot}4$ lbs., and a gallon of sea water weighs $10{\cdot}3$ lbs.

A Solid is a body that can bear longitudinal stress without lateral support. A Fluid cannot do so.—This definition is equivalent to the statement that a solid may be compressed or stretched without being supported at its sides; that, in fact, it possesses rigidity. A solid bar can exist, but not a fluid one. The cohesion stress between the particles of a solid is very great, and on account of its existence a solid cannot be easily broken, and is invariable in form.

Fluids are divided into two classes, called liquids and gases, neither of which possess rigidity.

A Liquid is a fluid such that if it is introduced into a vessel the volume of which is larger than its own, it will only fill a part of that vessel equal to its own volume.—A liquid is also characterised by the fact that it sets itself with a horizontal surface when all parts of that surface are under the same pressure. The cohesion stress is much less between the particles of a liquid than between those of a solid. It also differs in different liquids. If a V-shaped tube, containing nothing but water and its vapour, be adjusted as in Fig. 7, it will be found that the column of water can be supported in one arm of the tube because of the cohesion stress between the particles of water. In order to measure the force of cohesion, a flat glass or metal disc should be hung on one arm of a balance so as to touch the surface of the liquid under experiment, after wetting the plate with it. (Fig. 8.) Weights are then slowly added to the other arm of the balance until the liquid particles are separated. If water and alcohol be the liquids used, it will be found that the weights necessary to tear the liquids apart will be in the proportion of about 7 to 4. This is, therefore, the relative cohesion between the particles of water and alcohol. It is the force of cohesion which determines the size of drops—the greater the force the larger the drop, other circumstances being the same. Thus, if, say, 20 drops of water and 20 drops of alcohol be dropped from the bottoms of two globes of equal size, the volume of the water will be found to be almost twice

Fig. 7. Illustration of the cohesion stress between the particles of a liquid.

that of the alcohol because its cohesion is nearly twice as great.

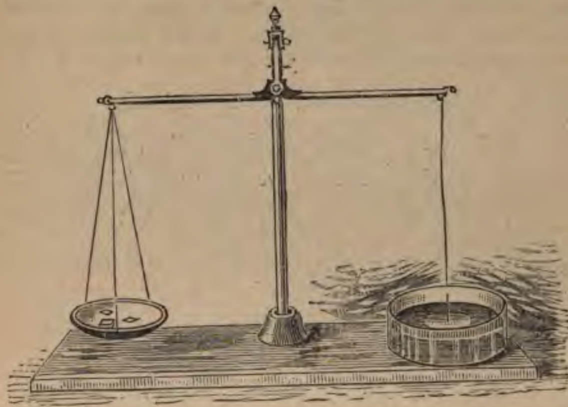


Fig. 8. How the force of cohesion is measured.

Dust some lycopodium powder over a slab of paraffin wax, and let drops of mercury and water fall upon it. Mercury has a greater cohesion than water, yet its drops will appear much flatter. This is because a drop of mercury is about fourteen times heavier than a drop of water of the same size. If the force of gravity suddenly ceased to exist, the two drops would become perfectly globular masses, having sizes proportional to the respective forces of cohesion.

But although the cohesion stress in liquids is sufficient to prevent them from disintegrating into the particles of which they are built up, it is not sufficient to give them that property called rigidity.

Liquids may be slightly compressed when subjected to very great pressures: they can also be stretched. In both these respects the behaviour is somewhat similar to that of solids, the difference being that liquids cannot bear such stress without lateral support.

The Pressure on any layer of liquid contained in an open vessel is proportional to its depth below the surface.—The weight of a cubic foot of water is $62\frac{1}{2}$ lbs. If, therefore, we have a vessel of water and immerse a square foot of some substance in the water at a depth of one foot, the pressure *it will be subjected* to will be the weight of the cubic foot of water

above it, that is, $62\frac{1}{2}$ lbs. At a depth of two feet the pressure would be doubled, at three feet trebled, and so on. Hence, if we were dealing with pure water, the pressure on any body at a depth of a mile, that is 5,280 feet, is $5,280 \times 62\frac{1}{2}$ or 330,000 lbs., which is equal to nearly 150 tons.

Capillary Elevation and Depression.—When a glass tube of small bore, and open at both ends, is dipped in a vessel containing water, or any other liquid that will wet it, it is found that the level of the water inside the tube is above the level of that outside, and that its surface is concave. If the tube be dipped in mercury, which does not wet it, it is found that the mercury inside will be below that outside and that it terminates in a convex surface. (Fig. 9.)

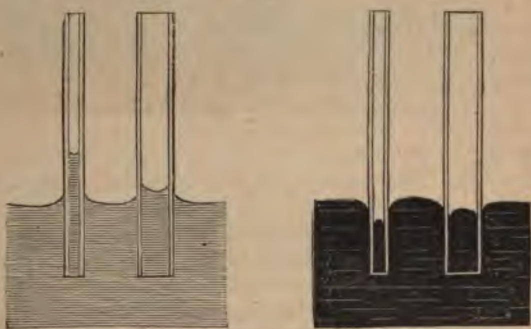


Fig. 9. Capillary elevation when tubes are placed in liquids which wet them, and depression when the tubes are not wetted by the liquid.

It can also be proved that in either case the elevation or depression is inversely proportional to the diameter of the tube, that is, if the diameter of a tube be halved, the elevation or the depression will be doubled. Phenomena of this kind are instances of *capillary action*. If one corner of a lump of sugar be dipped in water the numerous small pores act as capillary tubes, and the result is that the water ascends and moistens the whole lump.

The ascent of oil in lamp wicks, of water throughout the tissues of trees and plants, and the action of blotting paper, sponges, etc., are other illustrations of capillarity.

A Gas is a fluid such that if the smallest quantity of it be introduced into a vessel, the volume of which is larger than its own, it will distribute itself equally throughout all parts of the volume.—Gases have neither definite shape nor definite volume; that is, they have no surface, and fill any vessel into which they are placed. A gas cannot therefore be preserved in a vessel which is not shut in on all sides. Thus, if a cup containing any gas were placed in a room or in some vessel containing none, the gas would expand and fill the whole space. The volume and shape of a gas therefore simply depends upon the pressure to which it is subjected, and the vessel which contains it. No cohesion exists between the molecules of a gas, on the other hand the molecules appear to repel one another.

Fig. 10. Measurement of the relation between the volume and pressure of a gas (*Boyle's Law*).

The Kinetic Theory of Gases teaches that the molecules of a gas are continually moving about in all directions, and that the bombardment of the molecules against the sides of the containing vessel constitutes the pressure which the gas exerts. The pressure which a gas exerts therefore depends upon (1) the mass of its molecules, (2) their velocity, (3) the number of molecules. If one vessel contain twice as many molecules of gas as another of the same size, then, other conditions being the same, twice as many blows are struck on its sides, and its surface is under twice the amount of pressure. A similar increase of pressure can be produced by raising the temperature of a gas, in which case the rapidity with which the molecules move is increased, and therefore the number of blows struck upon the side of the vessel containing it is also increased. This brings us to a law discovered by Robert Boyle, viz., that *the volume of a given weight of any gas is inversely proportional to the pressure to which it is subjected, the temperature remaining constant.* This law is a consequence upon the fact that a perfect gas is perfectly elastic. If the pressure exerted upon a gas be doubled or trebled, the volume is reduced to one-half or one-third, if the pressure be decreased the volume of the gas is proportionally increased. (Fig. 10.)

A vapour is a substance which, under ordinary conditions, exists as a solid or liquid. Thus, water ordinarily exists as a liquid, but may be dissipated into the vapour we call steam by the application of heat. The gas used for illuminating purposes, and the air surrounding us, are called gases because they can only be converted into the liquid or solid form under great pressure and cold.

Sources of Heat.—The natural source of heat most important to us is the sun; the amount of heat we receive from it in a year being sufficient to melt a layer of ice 137 feet in thickness and covering the entire surface of the earth. Our artificial or terrestrial supplies of heat are almost wholly derived from chemical action, such as takes place when a fire is burning. But here again the ultimate source of heat is the sun, for its rays caused the growth of the plants which after lying for ages buried in the earth were transformed into coal. Another source of heat is mechanical friction, as when a bullet strikes against a target, or where brakes are applied to the wheels of a train. Electricity is also an important means by which heat is produced. It was supposed at one time that a body became hot owing to the presence of a weightless, invisible fluid called *caloric*, and that as the body cooled this fluid was squeezed out of it. We now know, however, that heat is only a condition of matter—a form of energy. A greater intensity of heat corresponds to a greater rapidity of movement of the molecules of a body. Part of the heat energy produces such effects as expansion or change of state, the remaining part produces vibrations in an invisible, weightless, elastic medium, which is supposed to pervade all space, and is called *ether*.

Distinction between Heat and Temperature.—Mix some hot and cold water. The mixture will not feel as hot as the hot water or as cold as the cold water employed, but intermediate between the two. This shows that when two bodies are placed in such situation that heat can pass from one to the other, the hotter always gives or tends to give up heat to the colder. If, when two bodies are placed in thermal communication, one of them loses and the other gains heat, that body which gives out heat is said to have a higher temperature than that which receives heat from it. We may therefore say that *the temperature of a body is its thermal state with reference to its power to communicate heat to other bodies*, or conversely, heat is that which, when communicated to a body, raises its temperature.

Temperature is a condition, and has a meaning precisely analogous to 'level' in liquids. Thus we speak of the water in a pond or a basin as being at a certain level, without any reference to the amount of water contained in either. In a like manner the temperature, or intensity of heat, in a red hot tin-tack may be the same as that in a red hot poker, or a thimblefull of water may have the same temperature as water in a lake. In either case the temperature has nothing to do with the total quantity of heat possessed by each.

The Specific Heat of a Substance is the quantity of heat required to raise one gramme or pound of that substance 1° C. in comparison with the amount of heat necessary to raise the same weight of water from 0° to 1° C.—Different substances require a different amount of heat to raise them in temperature to the same extent, hence different substances at the same temperature contain different quantities of heat. An exact understanding of this may be obtained by an analogy. Fill a large jug and a small jug with water up to the same height. Although the height is the same in each, we know that the large jug contains much more liquid than the small one, because it has a greater capacity. Now specific capacity for heat, or specific heat, has a precisely similar meaning to the capacity of a vessel to hold a liquid, and temperature is analogous to the height of the liquid. Water has about thirty times greater capacity for heat than mercury, hence a pound of water contains about thirty times the quantity of heat that is possessed by the same weight of mercury at the same temperature. If, therefore, equal weights of mercury and water be held in test tubes in a beaker (Fig. 11), and heated to the same temperature, and the two substances be

Fig. 11.
Arrangement for raising two liquids to the same temperature.

then poured quickly into two other beakers containing equal weights of cold water, the increase of temperature of the water into which the mercury was poured will be found to be about $\frac{1}{30}$ of the increase in the water to which the hot water in the test tube was added.

Take several balls or cylinders, of equal weights but different materials, *e.g.*, iron, copper, lead, bismuth, and heat them equally in an oil bath. Lay them simultaneously on a cake of beeswax about $\frac{1}{4}$-inch thick. Some of the balls will quickly melt the wax and fall through, while others will only sink slightly in it. It should be evident that the substance which first fell through possessed the greatest amount of heat, that is, had the highest specific heat. The order of falling through, and the relative depths to which the balls sink, therefore, expressed relative specific heats.

Water has the highest specific heat of all substances, hence it takes a long time to get hot and a long time to cool. On account of this circumstance water has a most important influence on climate, and so on the welfare of the living creatures on the globe.

The following are the specific heats of a few important substances:—

Water	1·000	Glass	0·198
Magnesium	0·245	Iron	0·112
Charcoal	0·241	Copper	0·095
Aluminium	0·202	Mercury	0·033
Sulphur	0·202	Lead	0·031

Expansion of Solids by Heat.—Almost all bodies, except those that are decomposed by heat, are expanded by it. The expansion of a solid body may be illustrated by fixing a

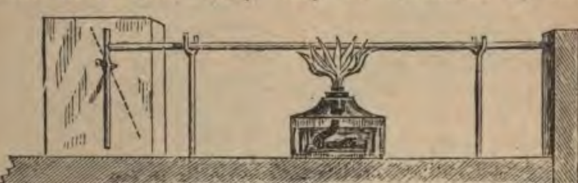


Fig. 12. Arrangement for proving that solids expand when heated.

rod of iron or some other metal so that one end is firm and the other touches a straw pivoted on a pin. (Fig. 12.) When

the bar is heated by means of a spirit lamp it expands and the slight push given to the short arm of the straw is considerably multiplied at the opposite end. Consecutive rails on railway lines are laid a little distance apart so that they may have room to expand in the summer. Iron bridges are also not built right up to the masonry at the sides on account of the fact that they increase in length when hot. But different solids have different expansibilities. Thus, if a brass and an iron wire, about 2 feet long, be soldered side by side, and then heated by means of a spirit lamp, they will be found to bend into a curve with the iron on the convex side. This shows that for the same increase of temperature iron expands more than brass. Similarly experiments may be repeated with other metals. Zinc has the greatest expansibility of ordinary metals, and platinum about the least.

Expansion of Liquids by Heat.—We cannot obtain a rod of liquid and determine its expansibility, but have to use a flask to hold it. In dealing with the expansion of liquids it must be remembered, therefore, that the vessel containing the liquid expands when heated, hence the visible expansion is the amount by which the expansion of the liquid exceeds that of the vessel containing it. If the expansibilities of the vessel and the liquid were equal, no increase would be observed. Fill three flasks with water, alcohol, and oil of turpentine respectively, and fit a cork having a glass tube open at both ends to each flask, so that the liquids stand at equal heights in the tubes. Put all the flasks in a vessel of warm water; the level of the liquid in the tubes first falls slightly, owing to the expansion of the flask, and then rises and remains steady. The alcohol will be found to rise very much more than the turpentine, and the turpentine nearly twice as much as the water. This shows that liquids, like solids, have unequal expansibilities. The most volatile liquids are often the most expansible. Thus alcohol expands about six times as much as mercury for the same increase of temperature.

Expansion of Gases by Heat.—The expansion of gases is simply illustrated by holding a bladder or a paper bag half filled with air near a fire. The expansion of the air will in time distend the bladder or bag. When withdrawn from the source of heat the air contracts, and the bladder again collapses. The expansion of gases may also be illustrated by *inverting* a flask, with a well-fitted cork and tube in its neck, into

a vessel containing some coloured water. (Fig. 13.) If the flask be warmed with the hand, the air expands and rises in bubbles to the surface of the water. When the hand is taken away the air contracts, and water rises in the stem at a certain level above that in the vessel. On bringing any source of heat near the flask the liquid descends, whilst a lump of ice makes it ascend. Such an instrument may, therefore, be used for estimating temperatures.

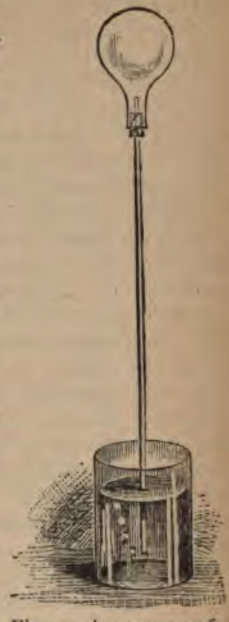


Fig. 13. Arrangement for proving that gases expand when heated.

Gases, unlike solids and liquids, expand equally for the same increase of temperature. Thus, if ordinary coal gas, or any other gas, were used in the above experiment, the same amount would be driven in bubbles out of the tube when it was heated by the hand.

Temperature cannot be accurately estimated by our sense of touch.—If one hand be plunged in hot water and the other in ice-cold water, and then both hands be held in lukewarm water, the hand that was held in hot water feels cold, and the hand that was held in cold water feels warm. It is also a matter of common knowledge that persons used to working in hot places feel cold, when others, used to working in colder places, experience the sensation of warmth. Inhabitants of equatorial regions find our average temperature cold, whilst people from the polar regions find it warm. The sense of touch is, therefore, not sufficiently delicate to rely upon for the measurement of temperature.

A Thermometer is an instrument used to measure temperature.—If it were possible to observe the variations in length of a bridge or railway line, we might use the bridge or metal to measure temperature. When the length increased we should know definitely that the temperature had also increased, and if a decrease in length were noted we could state that the temperature had decreased. A bar of metal might, therefore, be used as a thermometer, but it has the disadvantage of not being sufficiently

sensitive to slight variations in temperature, the amount of expansion of a steel bar 160 inches long between the temperatures of ice-cold water and boiling water being only $\frac{1}{8}$ of an inch. Liquids expand much more than solids for a given increase of temperature, and are, therefore, more suitable for thermometers.

How to construct a Mercurial Thermometer.—Procure a thermometer bulb and tube, or blow a strong bulb, about $\frac{3}{4}$ inch diameter, on the end of a piece of tubing having a fine bore. Heat the bulb gently over a flame and then immerse the open end in a cup of mercury; the mercury will enter the tube and bulb as the air cools. Repeat the heating until the bulb is very nearly filled with mercury, then shake together any small bubbles of air that remain clinging to the glass. Carefully heat the mercury until it boils; all the air is thus expelled and the bulb and tube should only contain mercury and mercury vapour. On cooling, the vapour condenses and mercury entirely fills the bulb and tube. When this is the case soften the glass by means of a blow-pipe flame and draw out the end of the tube to a narrow thread. Heat the bulb to a temperature slightly higher than that required to be registered. Then seal off quickly by the blow-pipe and take away the burner heating the bulb. As the mercury cools it contracts, leaving a space filled with its vapour at the upper end of the tube, while the liquid occupies only the bulb and part of the stem at ordinary temperatures. The lengthening or shortening of the column of mercury in the glass tube give us a means of measuring temperature.

How to Graduate a Thermometer.—Immerse the thermometer in some ice and water, contained in a funnel having a piece of indiarubber tubing fixed to its neck. A pinch cock may be arranged so that the tubing can be opened or closed at will, in order to adjust the *quantity* of water. (Fig. 14.)

Fig. 14.
Determination of the freezing point of a thermometer.

The mercury in the stem of the thermometer will be found to contract, and after a time remain steady at a certain point. Mark this fixed point by tying a piece of cotton round the stem and adjusting it at the same height as the mercury. The temperature thus registered is the 'freezing point' of water, that is, the temperature at which water is transformed into ice, or *vice versa.*

Fig. 15.
Determination of the boiling point of a thermometer.

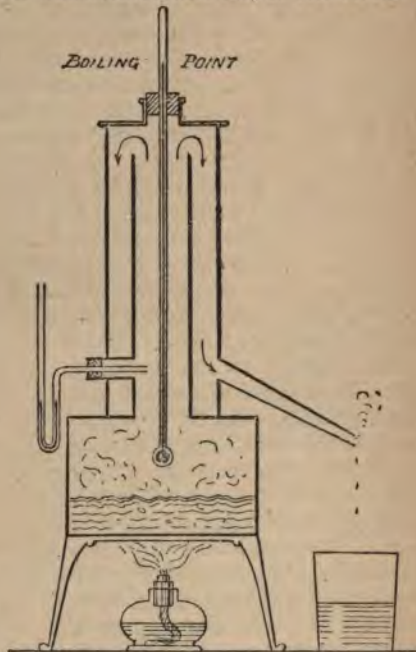


Fig. 16. Arrangement for accurately determining the boiling point of a thermometer.

Another 'fixed point' that may be employed for the graduation of a mercurial thermometer, is the temperature at which water boils at sea level and under the ordinary atmospheric pressure. To determine the length of the column of mercury at this temperature, bore two holes in the cork of an 8 oz. flask and fit the thermometer in one, and a piece of glass tubing, bent at a right angle, in the other. Pour some water into the flask and boil it by means of a spirit lamp. (*Fig.* 15.) When steam has been coming off freely

for about 10 minutes, and the mercury appears steady, tie another piece of cotton round the tube on a level with the end of the column. This indicates the 'boiling point' of water. In order to obtain this temperature very accurately it is necessary to employ apparatus such as that illustrated in Fig. 16. We have now two fixed points represented by two circles of cotton on the stem of the thermometer. The distance separating these two points evidently depends on the amount of mercury which is expelled from the bulb in passing to the higher temperature, and the internal diameter of the stem. If two thermometers have bulbs of equal capacity, but stems of different bores, the increase of length of the column of mercury for a given increase of temperature would be more in the narrow-bored stem than in the wide one. If, therefore, the bore be fine enough, a large rise of the column of mercury may be caused by a comparatively small elevation of temperature. The thermometer is then said to be a sensitive one.

Thermometric Scales.—The interval between the boiling and freezing points of water indicated on the thermometer may be divided into any number of parts or 'degrees,' and if the bore of the stem has the same diameter throughout, the degrees should be of the same length, for mercury has a uniform rate of expansion between the limits of temperature we have employed. In England we use the Fahrenheit thermometer, in which the freezing point of water is indicated by 32 degrees, written 32°, and the boiling point by 212°, the interval being thus divided into 180°. In France, and for scientific work, the Centigrade thermometer is used, in which the freezing and boiling points of water are respectively indicated by 0° and 100°. The Reaumur thermometer is used in some parts of the Continent, and marks these points by 0° and 80°. The relation between the Fahrenheit (F), Centigrade (C), and Reaumur (R) scales is shown in Fig. 17, from which it appears

$$\text{that} \quad 180^\circ\ F = 100^\circ\ C = 80^\circ\ R.$$
$$\text{hence} \quad 9^\circ\ F = 5^\circ\ C = 4^\circ\ R.$$

If, therefore, a thermometer could be graduated in each of the three ways, we should find the Centigrade degrees nine-fifths as long as the Fahrenheit ones, and the Reaumur degrees five-fourths as long as the Centigrade ones. In order to convert readings of the Reaumur scale to the Centigrade scale, we must *multiply* them by $\frac{5}{4}$, thus 40° R. $= (40^\circ \times \frac{5}{4})$ C $= 50^\circ$ C. To

convert Centigrade readings into Reaumur, we must multiply by $\frac{4}{5}$, thus 35° C = $(35^\circ \times \frac{4}{5})$ R. = 28° R.

Fahrenheit readings may be converted into Centigrade or Reaumur by subtracting 32 and then multiplying by $\frac{5}{9}$ and $\frac{4}{9}$ respectively, thus 95° F = $(95 - 32)\frac{5}{9}$ C = $63 \times \frac{5}{9}$ C = 35° C Similarly, 95° F will be found to equal 28° R.

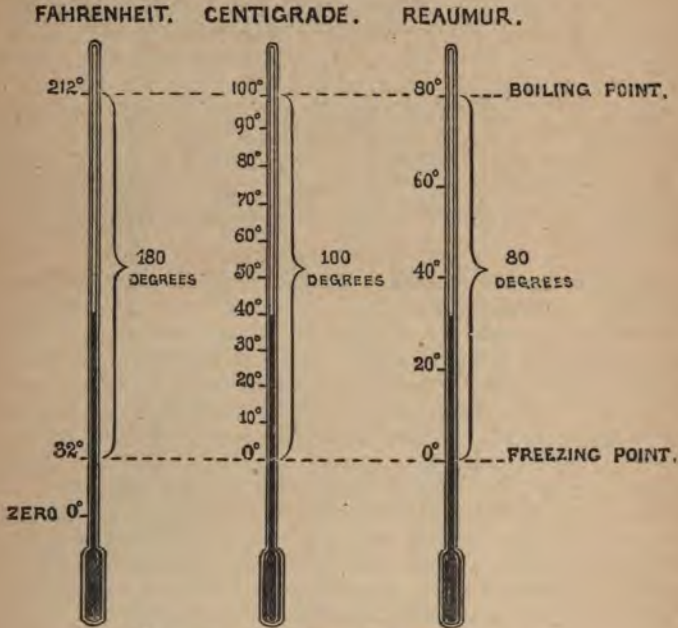


Fig. 17. Thermometer Scales.

Centigrade or Reaumur readings may be converted into Fahrenheit by multiplying by $\frac{9}{5}$ or $\frac{9}{4}$ and adding 32 to the quotient, thus 60° C. = $(60 \times \frac{9}{5}) + 32$ F. = $(108 + 32)$ F. = 140° F. In like manner 60° R. = $(60 \times \frac{9}{4}) + 32$ F. = $(135 + 32)$F. = 167° F.

The following equations sum up the above described relations.

$$R. = \tfrac{4}{5}\,C. = \tfrac{4}{9}\,(F - 32)$$
$$C. = \tfrac{5}{4}\,R. = \tfrac{5}{9}\,(F. - 32)$$
$$F. - 32 = \tfrac{9}{5}\,C. = \tfrac{9}{4}\,R.$$

Mercury is generally used in the Construction of Thermometers for the following reasons:—

(1) *It remains liquid throughout a long range of temperature.*

The freezing point of mercury is $-40°$ C. ($-40°$ F.), the boiling point is 350° C. (662° F.); hence the range is 390° C. or 702° F. Alcohol freezes at $-98°$ C. ($-209°$ F.), and boils at 78° C. (174° F.); its range is, therefore, 176° C. or 383° F., that is, only about half as great as mercury.

(2) *Its rate of expansion is practically constant between — 36° C. and 100° C.*

Many liquids expand more than mercury for the same increase of temperature. In general, however, the amount which a liquid expands for one degree of temperature increases considerably with the temperature. The degrees on a thermometer ought, therefore, to gradually increase in length from zero. It is much easier, however, to make the degrees of equal length, hence the almost equal rate of expansion of mercury between the above-named temperatures is very useful.

(3) *It has a low specific heat.*

The specific heat of a substance is the amount of heat required to raise its temperature one degree with reference to the amount required to raise the same weight of water through the same temperature. On account of the low specific heat of mercury, a much smaller amount of heat is required to raise its temperature than is necessary to similarly raise the temperature of an equal amount of water or alcohol; hence, when a mercury thermometer is used to test the temperature of a body it only uses up a very small quantity of the heat which the body possesses.

(4) *It is a good conductor of heat.*

On account of this property, mercury quickly acquires the temperature of the body with which it is in contact.

(5) *It does not wet the glass in which it is contained.*

A water or alcohol thermometer has to be held a short time after being cooled before the temperature can be read off, for those liquids wet the glass which contains them, and the amount of liquid left sticking to the sides of the tube as the column contracts, must have time to trickle down and add to the reading obtained. In a mercury thermometer no liquid is left behind as the column contracts when cooled.

(6) *It can easily be seen against the glass.*

Alcohol is often used in thermometers, and especially for those designed to measure temperatures below the freezing point of mercury. The boiling point of alcohol is 78° C., so that it cannot be employed at high temperatures. An alcohol thermometer graduated according to the Fahrenheit and Centigrade scale is shown in Fig. 18.

Fig. 18.
An Alcohol Thermometer.

A Maximum Thermometer indicates the highest temperature to which it has been exposed since it was adjusted.—There are several forms of maximum thermometers, but one of the best is Negretti & Zambra's. Fig. 19. It consists of an ordinary thermometer bulb and tube, having a small piece of solid glass enamel inserted in the bend of the tube above the bulb. When the mercury is expanded by heat it squeezes past the piece of glass and causes the end of the column to advance along the scale. When, however, the mercury is cooled it contracts, and the column breaks at the point where the

Fig. 19. Negretti and Zambra's Maximum Thermometer.

glass enamel is inserted. The end of the column then registers the maximum temperature attained. In order to adjust the instrument for future observation it must be held bulb downwards and swung with a gentle pendulum motion; the mercury will then descend in the tube and meet that contained in the bulb.

A Minimum Thermometer indicates the lowest temperature to which it has been exposed since adjustment.—Alcohol is generally used in minimum thermometers. An instrument of this kind is shown in Fig. 20. It consists of a glass

Fig. 20. Negretti and Zambra's Minimum Thermometer.

tube having a bulb and part of the stem filled with spirits of wine in which floats a black index, having somewhat the shape of a dumb-bell. If the thermometer be held bulb upwards the index falls to the surface of the alcohol, but does not burst through it. When the instrument is hung in its proper position a decrease of temperature causes the alcohol to contract, and the surface drags back the index with it; on an increase of temperature the alcohol expands, and the end of the column advances along the scale. The index, however, is left behind, and the end of it furthest from the bulb indicates the lowest temperature *reached.*

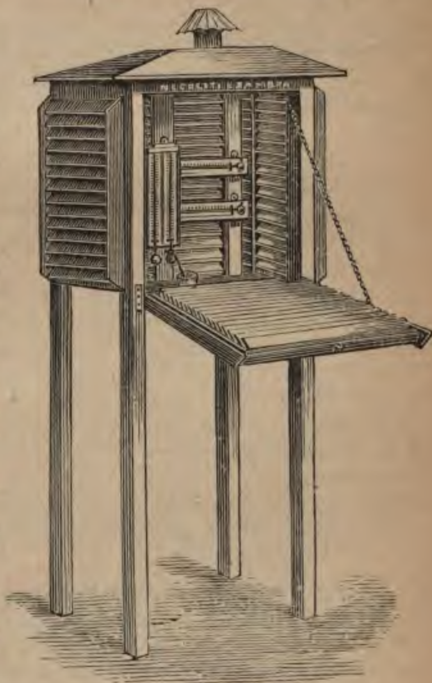


Fig. 21. Maximum and Minimum Thermometers and a Wet and Dry Bulb Thermometer in a Stevenson's cage.

For accurate meteorological work the maximum and minimum thermometers are kept in a specially constructed cage to shield them from the sun. (Fig. 21.) The figure shows also an instrument used for the estimation of the moisture in the air.

A Solar Radiation Thermometer is one used to determine the intensity of the sun's heat in the position where it is placed.—This instrument consists of a maximum thermometer having its bulb and a part of the stem covered with lamp-black, and enclosed in a glass tube and globe from which the air has been pumped. (Fig. 22.) The whole is generally supported about 4 feet from the ground, and exposed

Fig. 22. A Thermometer for measuring the intensity of the sun's heat (Negretti and Zambra's).

to the sun's rays. Lamp-black is a good absorber of heat, and all the sun's rays which fall upon the blackened bulb and stem go to raise the temperature of the thermometer. The vacuum prevents the loss of heat by air currents, to which an ordinary thermometer is subjected. If placed side by side with an exposed bulb thermometer, the black bulb thermometer indicates a temperature about 20° F. or 30° F. higher. The difference between the readings of the two instruments is an indication of the intensity of heat received directly from the sun during observation.

Heat is transferred from one portion of matter to another in three ways, which are called respectively *conduction*, *convection*, and *radiation*.

The conductivity of a substance for heat is measured by the facility with which heat is transferred through it.—We know that if a poker be left in the fire the handle gets very hot, whilst a piece of wood similarly placed may be touched until it is almost entirely consumed. This is because of the different powers of conducting heat possessed by the particles of which these bodies are composed. To show the different con-

ductivities of iron and copper, take a wire of each of these substances, about 6 inches long, and twist them together at one end. Fasten with beeswax one or two marbles on each wire at about 4 inches from the joint. Now heat the joint in a flame. The marble on the copper will be seen to drop before the equidistant one on the iron, thus indicating that copper is the better conductor. The following are the relative conductivities of a few metals :—

Silver	100·0	Iron	11·9
Copper	74·8	Platinum	8·4
Gold	53·2	Lead	7·9
Tin	15·4	Bismuth	1·8

Wood, cork, feathers, down, fur, flannel, and similar substances have extremely low conductivities, and are therefore termed bad conductors. The negative properties of these fabrics render them useful for winter dresses and other purposes where it is required to prevent the transference of heat. Our clothes, or the blankets in beds, do not make us warm, but prevent the escape of heat from our bodies to the air surrounding us. Similarly, ice may be kept in a blanket or in sawdust for a considerable time, because such substances are bad conductors, and therefore more or less prevent the passage of heat from the air to the ice.

Liquids are far worse conductors than most solids. In illustration of this, place a piece of ice in a long test tube, and weight it down with a piece of lead. Nearly fill the test tube with water and hold it obliquely over the flame of a spirit lamp or Bunsen burner. It will be found possible to boil the water without melting the ice, thus showing that the water does not readily conduct heat, although it conducts better than any other liquid except mercury.

The low conductivity of gases may be demonstrated by placing a little powdered lime in the palm of the hand, and resting the end of a red hot poker upon it. The air amongst the particles of lime will not conduct the heat of the poker to the hand, but if a solid piece of lime, about $\frac{1}{4}$ inch thick, be substituted for the powdered lime, the heat of the poker will soon be felt.

The low conductivity of fur, down, flannel, &c., is mainly due to the air which is enclosed in the material and thereby prevented from movement. If such substances be compressed into sheets so that most of the air is expelled, they will be found to be much better conductors.

Convection is the carrying of Heat by particles of matter raised in temperature and set in motion.—Take a round bottomed flask filled with water and drop a few fragments of solid blue litmus, aniline dye, or cochineal to it. Heat the flask over a flame. The coloured water will be observed to rise to the surface, when it will bend over in every direction, and form a number of descending currents. (Fig. 23.) These currents result from the fact that a portion of warm liquid is lighter than an equal volume of cold liquid, consequently when the particles of liquid at the bottom of the flask are heated, they become specifically lighter and ascend, colder and therefore heavier particles descending to take their place. All the particles are thus in turn brought to the source of heat and kept in visible motion until the whole of the liquid is at the same temperature, which occurs on boiling. Of course the lamp need not be placed in the middle of the bottom of the flask in order to set up convection currents. If a test tube containing some ice be held in the top of the liquid, precisely similar currents are set up, the ice cooling the particles near it, and thus increasing their specific gravity, the result being that they descend and less dense particles take their place until thermal equilibrium is restored. Gases are raised in temperature in exactly the same way as liquids.

Fig. 23. Convection currents in liquids.

When a fire burns it is heating the air near it, and the heated air ascends up the chimney because it is specifically lighter; cold air then rushes in from all sides to take the place of the heated air—thus so long as the fire burns a circulation is kept up, *currents of air from* the outside forcing themselves through the *walls and crevices* of the room to the source of heat, and then

being sent up the chimney. If the chimney be stopped up or anything done to prevent this free circulation the fire goes out; if anything be done to concentrate the current upon the burning coals—such as the common practice of holding a newspaper across the fire-grate—the fire burns brighter.

It would be expected from what we have said that under any circumstances, in a room or in the open air, the hotter air will occur at a higher level than the colder, and that so long as this difference in density exists currents will be set up from the cold air to the hot. That such is the case is capable of easy demonstration. Hold a candle first at the top and then at the bottom of the open door of a warm room (Fig. 24); when at the top the flame will be blown outwards, while at the bottom it will be blown inwards, and it can be shown that the current going outwards is warmer than the inward current. We thus see that by the action of heat a circulation of air may be set up.

Fig. 24. Convection Currents in Gases.

Radiation is the process by which the energy of heat is transferred from one body to another through space.—In conduction, the particles of a body are supposed to pass on their heat to those at a lower temperature in physical contact with them. In convection, the particles carry the heat they receive to different parts of the liquid or gas. In radiation, however, heat *may be transmitted* from one body to another without affecting

the temperature of the intervening medium and independently of the existence of such. It is by radiation that the earth receives heat from the sun. The heat vibrations set up by our luminary travel through space with the same velocity as those of light—186,000 miles per second. In fact, heat and light only differ from each other in the velocity of vibration. Thus when a rod of iron or a wire of platinum is heated, it first sends out rays of heat which affect the touch but do not visibly affect the eye; on continued heating, however, we see a few red rays and say that the body is red-hot. It is then emitting both light and heat rays. As the temperature is still further increased, the body passes to a yellow tinge, and then radiates a white heat which may be used for illuminating purposes. We may therefore conveniently say that heat is radiated in *dark rays*, that is, with light absent, and *luminous rays* in which the light is a sort of elevated heat, the two phenomena obeying precisely the same laws.

Water contained in a kettle covered with soot, gets hot much quicker than that contained in a bright kettle of the same size subjected to the same source of heat. Experiments show that lamp-black or soot is the best possible absorber of heat, and polished surfaces the worst. This therefore accounts for the different temperatures of the water in the two kettles.

Again, if the same amount of hot water be poured in two vessels, one of which is covered with soot and the other polished, the water in the blackened vessel will be found to cool twice as fast as that contained in the bright vessel. The cooling has mainly taken place by radiation, hence we can say that lamp-black is a better radiator than polished metal. Bright tea-pots and coffee-pots and polished dish covers are therefore not merely bright for ornamental purposes, for as they lose their brightness they lose the quality of being bad radiators. Observations have brought out the important fact that *good radiators are good absorbers*, hence if we know the relative radiating powers of two bodies we also know their relative absorptive powers.

QUESTIONS ON CHAPTER II.

1. Define solids, liquids, and gases. What internal changes occur when a lump of ice is converted into water and the water into steam.

2. Define cohesion, and describe experiments illustrating the cohesion stress between the molecules of a liquid.

3. *What is the* '*kinetic* theory of gases?' State Boyle's law, and describe *how it may be experimentally* proved.

4. Define density and specific gravity.. How would you find the specific gravity of a lump of lead, and of some brandy ?

5. Define strain, and give illustrations of its meaning.

6. Define elasticity, tenacity, and ductility. Which is more elastic, glass or india-rubber?

7. Define malleability, hardness, and viscosity. What is meant by 'capillary elevation and depression ?'

8. What is the pressure on an area of three square feet immersed 100 feet below the surface of a lake?

9. Why is mercury used in thermometers? (1887.)

10. What is a maximum and minimum thermometer, and for what purposes is it used? Describe any form of the instrument with which you are acquainted. (1886.)

11. Describe the construction and use of a thermometer, and explain the methods by which thermometers are graduated. (1880.)

12. Describe the principle of the construction of the mercurial thermometer. (1879.)

13. Describe methods of proving that solids, liquids, and gases expand when their temperature is increased.

14. What is 'specific heat'?

CHAPTER III.

CHEMICAL PROPERTIES OF MATTER.

Chemistry is that branch of science which investigates the composition of different kinds of matter, and their mutual action to form bodies differing from themselves.—The general properties of matter have been discussed in previous chapters. We have now to deal with the question of the causes of the difference in properties, which distinguishes such substances as sugar and salt, or water and oil, from each other. The first question that presents itself is: Are the innumerable substances which are found in our globe made up of one kind of matter, or several? In order to obtain information on this point, we must subject substances to the action of various forces. We should then find that all forms of matter may be divided into two great classes, compound bodies and simple or elementary ones. The resolution of a body into its constituent elements is termed *analysis*, whilst the putting together of elements to form a compound substance is known as *synthesis*.

A compound substance is one which the chemist can split up into two or more essentially different materials.—Put a little red oxide of mercury (mercuric oxide) into a test tube, and heat it over a flame. In a short time the substance darkens, and a mirror-like coating appears on the cooler sides of the tube. Further, if a lighted match or taper be plunged into the tube it will burn with increased vigour, and if a glowing match be introduced it will be rekindled. This experiment, or analysis, proves to us that by heating a substance called red oxide of mercury, we obtain a metallic deposit, which on examination proves to be mercury, and a colourless gas called oxygen, which is capable of supporting combustion. If the mercury and the oxygen were very accurately weighed, the sum of their weights

would be found to be exactly equal to the weight of the red oxide of mercury which was decomposed. There has been no loss of matter, but only a change into different forms.

Now whatever we do to the mercury or the oxygen, we can get nothing but mercury or oxygen from them. It is just possible that some day chemists may decompose them, but this cannot be done by any means now at our disposal, and so we call them simple or elementary substances, or *elements*.

The Latin name for mercury is Hydrargyrum. In chemical work it is found convenient to abbreviate the English or Latin names of elements. We therefore write Hg for mercury, and O for oxygen. Since the red oxide of mercury consists of mercury and oxygen, can represent it by the formula HgO. Hence, instead of expressing the result of the above experiment in the words, Mercuric Oxide yields Mercury and Oxygen, we could symbolise it thus :—

$$HgO = Hg + O$$

Such an expression is called a chemical equation. The sign = signifies 'yields' or 'produces;' and the + sign has its ordinary plus or additive meaning.

In like manner, by the action of electricity, water may be decomposed into the two elementary gases, hydrogen and oxygen, in the proportion of two volumes of the former to one of the latter. This change is expressed by the equation :—

$$\underset{\text{Water}}{H_2O} = \underset{\text{Hydrogen}}{H_2} + \underset{\text{Oxygen}}{O.}$$

Mechanical Mixtures and Chemical Compounds.— If some flowers of sulphur and copper filings be well shaken together, the two substances appear to lose their characteristic colours and a mixture of a greenish tint is obtained. The only observable difference, when varying proportions of sulphur and copper are employed, is a change of tint. But however intimately the two substances may be mixed, it is possible, by the help of the microscope, to pick the particles of copper from the particles of sulphur; or the two may be separated by throwing the mixture into water, for the sulphur will then float on the surface and the copper will sink. In such a case as this, when elements can be mechanically separated one from the other, the bodies in question are said to be mechanically mixed. Now heat some of the mixture in a test tube. In a few moments a glow will spread through it, the sulphur and copper lose their characteristic proper-

ties, and a black substance, entirely different from either of them, remains in their stead. If this substance be examined with the most powerful microscope it will be found to present a uniform appearance in which the sulphur and copper particles cannot be distinguished as they could previous to the heating. The change thus observed is a chemical one, and the result of *chemical action*. The sulphur and the copper combine chemically with each other and form a *chemical compound*. By certain means this compound can be analysed, that is, the sulphur can be again separated from the copper, and it is found that, whatever the proportion of the two elements mixed together and heated, the compound formed always contains 80 per cent. of copper and 20 per cent. of sulphur. (To be more accurate the proportion is 79·8 to 20·2.) If more than this proportion of either element is used it is left behind in the test tube. Similarly, gunpowder is a mixture of nitre, charcoal, and sulphur. But however intimately these ingredients may be mixed, the nitre can be dissolved out of the mixture by water, the sulphur by carbon bisulphide, and the charcoal will be left. As soon as the gunpowder is ignited, however, a chemical change occurs, and various new substances, several of which are gases, are immediately formed.

The differences between a mechanical mixture and a chemical compound may, therefore, be summed up as follows:—

Mechanical Mixtures.	*Chemical Compounds.*
The ingredients may be separated by mechanical means.	The ingredients cannot be separated by mechanical means.
Any proportion may be mixed together.	A definite proportion of the ingredients is always taken up.
The properties are intermediate between those of the ingredients.	The properties are essentially different from those of the ingredients.

Elements, or Simple Substances, are those from which the Chemist can only obtain one ingredient.—From pure gold nothing essentially different from gold can be obtained, whatever form of energy it is subjected to. Similarly, mercury, or the gases oxygen or hydrogen, previously referred to, resist all efforts made to decompose them. These are examples of the bodies we call elements. In fact, every substance with which we are acquainted is made up of one or more of about

75 elements. For the sake of convenience these elementary bodies are divided into two classes called *metals* and *non-metals or metalloids*. The following is a complete list of the non-metals and the most important metals:—

Non-metallic Elements.

Name of Element.	Chemical Symbol.	Atomic Weight.
Boron	B.	10·9
Bromine	Br.	79·76
Carbon	C.	11·97
Chlorine	Cl.	35·37
Fluorine	F.	19·06
Hydrogen	H.	1
Iodine	I.	126·54
Nitrogen	N.	14·01
Oxygen	O.	15·96
Phosphorus	P.	30·96
Selenium	Se.	78·87
Silicon	Si.	28·0
Sulphur	S.	31·98

Important Metallic Elements.

Name of Element.	Chemical Symbol.	Atomic Weight.
Aluminium	Al.	27·04
Antimony	Sb.	119·6
Arsenic	As.	74·9
Barium	Ba.	136·86
Bismuth	Bi.	207·5
Calcium	Ca.	39·91
Chromium	Cr.	52·06
Cobalt	Co.	58·6
Copper	Cu.	63·18
Gold	Au.	196·85
Iron	Fe.	55·88
Lead	Pb.	206·39
Magnesium	Mg.	23·94
Manganese	Mn.	54·8
Mercury	Hg.	199·8
Nickel	Ni.	58·6
Platinum	Pt.	194·3
Potassium	K.	39·03
Silver	Ag.	107·66
Sodium	Na.	22·99
Strontium	Sr.	87·3
Tin	Sn.	117·35
Zinc	Zn.	64·88

Compound bodies bear the same relation to elementary ones that the words of our language bear to the letters which form them. The twenty-six letters of our alphabet are used to construct words. Some letters occur very frequently, and others very rarely. In like manner the seventy-five chemical elements build up innumerable compounds, some elements entering into composition more frequently than others. Water, being composed of two elements, oxygen and hydrogen, is analogous to a word of two letters; salt is made up of sodium and a gas chlorine, and represents a word of two different letters. Three elements, calcium, carbon, and oxygen, are found in chalk, which is therefore like a word of three letters.

E

An atom is a portion of matter which cannot be sub-divided into more elementary parts by any process at present known to science.—It is supposed that every element is made up of an infinite number of atoms, having the same size and weight in the same body. If it were possible to obtain atoms of the elements and weigh them separately, we should find that the atom of hydrogen weighed the least. Calling this weight 1, the atom of oxygen would be found to weigh 16, the atom of phosphorus 31, and the atom of mercury 200. The *atomic weights*, which are given in the tables of elements, represent the weights of particular atoms, and are of the highest importance. And here we must mention that the abbreviated names, or chemical symbols, not only stand for the names of elements but for definite weights. Thus, if H stands for 1 gram, or 1 pound, or 1 ton, or any other unit weight of hydrogen, O stands for 16 grams, pounds, or tons, etc., of oxygen, and Hg stands for 200 grams, pounds, or tons, etc., of mercury, and so on for any other element. If H_2, or O_2, or C_4, be written, it signifies that two atoms of hydrogen or oxygen and four atoms of carbon have to be considered.

A molecule is a group of atoms.—An atom cannot exist by itself, but in general is connected with one or more like or unlike atoms, the group thus formed being called a molecule. The minutest portion which it is possible to obtain of any substance is composed of a vast number of such groups of atoms or molecules, the members of each of which are so connected that they move about together, whilst the movements of the groups themselves are independent of each other. All the atoms of any particular element are alike, and the molecules of an element consist of groupings of like atoms. Thus, a molecule of hydrogen is made up of two atoms of the gas (H_2), and a molecule of arsenic contains four atoms to a molecule (As_4). Chemical compounds are formed of innumerable groups of unlike atoms. Thus, a molecule of water is composed of two atoms of hydrogen united to one of oxygen (H_2O), and every molecule of sugar contains twelve atoms of carbon, twenty-two atoms of hydrogen, and eleven atoms of oxygen ($C_{12}H_{22}O_{11}$). If such groups are split up, and different arrangements of atoms created, the substance no longer possesses its characteristic properties. We may therefore say that a molecule is the smallest *part of a simple* or compound substance which can exist in a free *state, and possess the* properties of that substance.

When chemical changes occur, the molecules of the substances engaged act upon each other, and a re-arrangement of atomic positions is the result.

Chemical affinity is the attraction stress which acts between the atoms of substances.—The atoms in a molecule are held together by a mutual attraction or stress termed *chemical affinity*. This stress, unlike cohesion, is strongest between the atoms of dissimilar substances. It also differs from cohesion in acting between atoms instead of molecules. A grain of sand consists of an infinite number of molecules bound together by the cohesion stress, and each molecule is made up of two atoms of oxygen and one of silicon bound together by the stress called chemical affinity. In the same way that persons have an affinity for particular individuals, the atoms of elements have their respective likes and dislikes. If a small piece of the metal sodium, which has a great affinity for oxygen, be thrown into water, a gas is evolved which burns when a lighted taper is brought near it, and possesses all the properties of hydrogen. The oxygen in the molecules of water (H_2O) has a greater affinity for sodium (Na) than for hydrogen (H), so the liquid is decomposed, the oxygen atoms leaving the hydrogen atoms to which they were joined, in order to unite with atoms of sodium and form a new compound.

Similarly, when steam and chlorine gas are passed together through a red-hot tube, the hydrogen atoms separate from those of oxygen and unite to atoms of chlorine, because the chemical stress between hydrogen and chlorine is greater than between hydrogen and oxygen.

As another example of the breaking up of the molecules of a body, let some sulphuric acid (oil of vitriol) be dropped upon a lump of sugar ($C_{12}H_{22}O_{11}$). The acid has a great affinity for water, and exercises it upon the sugar with the result that a black mass consisting solely of carbon is left.

Heat is perhaps the most common form of energy which the chemist employs to break up molecular groupings. The action of this agent has already been demonstrated by experiments on mercuric oxide, and a mixture of copper and sulphur. The formation of lime from limestone is a further exemplification. When marble or limestone is strongly heated, as it is every day in our lime-kilns, a gas called carbon dioxide, or carbonic acid gas, is driven off and the familiar body, quicklime, remains in the kilns. If the limestone and quicklime were each weighed it would be

found that the former yielded about 56 per cent. of the latter, whilst the remaining weight passed off into the air. Experiments show that the molecules of the gas evolved when limestone is burnt, consist of an atom of carbon (C) united to two atoms of oxygen (O_2). Each molecule of lime is made up of an atom of the metal calcium (Ca) united to an atom of the gas oxygen (O).

The change which resulted from heating limestone may therefore be written thus :—

$$\underset{\text{Limestone.}}{CaCO_3} = \underset{\text{Quicklime.}}{CaO} + \underset{\text{Carbon dioxide.}}{CO_2}$$

The action of electricity in breaking up a compound (water) has already been referred to. It should also be mentioned that the whole art of photography depends upon the action of light in decomposing certain compounds of silver.

OXYGEN.

Atomic Symbol, O. Atomic Weight, 16.
Density (Air = 1) = 1·105.

In 1774 Dr. Priestley found that when a beam of sunlight was concentrated upon some mercuric oxide (HgO), a gas was given off. This gas was oxygen, and its isolation was due to the breaking up of the compound into its constituents—mercury and oxygen. It is now known to be the most widely diffused element in nature. It exists uncombined as one-fifth of the volume of the air which surrounds us, whilst eight-ninths of the weight of water on our globe consists of oxygen in combination with hydrogen. The earth's crust contains about 46 per cent. of this element in combination with other substances, and it forms more than one-half of the substance of plants and animals.

Preparation of Oxygen.—Oxygen is best obtained from a compound called Potassium Chlorate, which is composed of the elements potassium (K), chlorine (Cl), and oxygen (O), and has the formula $KClO_3$. This body melts at about 370° C., and at about 400° C. it begins to give off oxygen.

Place a few crystals of potassium chlorate in a test-tube and heat them gently over a Bunsen flame. In a short time the crystals begin to fuse, and a gas is evolved which will re-ignite a glowing match, as is also the case when mercuric oxide is heated. This substance is oxygen gas. The pasty mass left in the test-tube can be proved to be mainly potassium chloride (KCl).

The chemical change which takes place is therefore expressed by the equation

Potassium Chlorate		Potassium Chloride		Oxygen
$2KClO_3$	$=$	$2KCl$	$+$	$3O_2$

By using some such substance as sand, manganese dioxide (MnO_2), or red oxide of iron (FeO), mixed with the potassium chlorate, the gas comes off more copiously and at a much lower temperature. In order to prepare a large quantity of the gas, a more convenient arrangement than a test-tube is necessary. Fit a bored cork in a small glass flask. Bend a piece of glass tubing in a gas flame, and pass one end through the cork. Bend another bit of glass tubing and connect the two by means of a short piece of india-rubber tubing. Now mix some dry powdered potassium chlorate with about one-third its weight of manganese dioxide, and introduce the mixture into the flask. Support the flask with the cork in its neck in the manner shown in Fig. 25. The pneu-

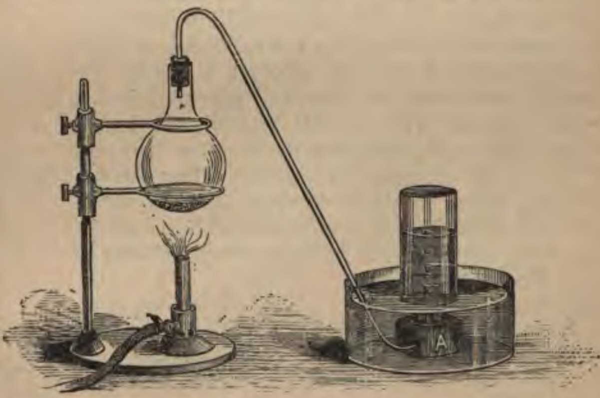


Fig. 25. Arrangement for producing and collecting a quantity of Oxygen.

matic trough there indicated, facilitates the collecting of the gas. It consists of an ordinary circular iron or earthenware trough in which is placed a beehive shaped shelf (A) having an opening at the side through which to pass a delivery tube, and a hole at the top through which the gas bubbles. A glass jar or bottle should now be filled with water and stood over the hole in the beehive shelf with its mouth under water. All being ready, the flask is

gently heated; the air is first expanded by the heat and escapes from the delivery tube. Soon afterwards the issuing gas will re-kindle a glowing match. It may then be collected by letting it bubble up through the hole in the top of the beehive shelf. When full the bottle may be removed from the shelf by slipping a glass plate over its mouth. Several bottles of pure oxygen gas can be thus obtained.

Properties of Oxygen.—Pure oxygen has neither colour, smell, nor taste. It is heavier than air in the proportion of 11 to 10. It can be transformed into a sky blue liquid by a pressure of 2,800 lbs. to the square inch and a temperature of—140° C. Water dissolves about 3 per cent. of its volume of the gas at 15° C. This is a comparatively small proportion, nevertheless it is a property of oxygen of first importance to the animal and vegetable kingdom. Fishes die if placed in water which contains no oxygen.

That substances burn in oxygen with considerable energy, has already been experimentally proved. In further illustration of this, place a piece of roll sulphur in a *deflagrating spoon* (Fig. 26), set it on fire by touching it with a red-hot wire, and plunge it into a bottle of oxygen. The sulphur immediately bursts into a rich lilac flame, considerably brighter than that given by sulphur burning in ordinary air. An invisible gas, called sulphur dioxide and having a pungent odour is formed by the combination of the sulphur with oxygen. Its formula can be shown to be SO_2. We have therefore

Fig. 26. A deflagrating Spoon.

Sulphur.		Oxygen.		Sulphur Dioxide.
S	$+$	O_2	$=$	SO_2
32	$+$	2×16		$32 + 2 \times 16$
		64		64

This equation shows that if we add up the atomic weights of the elements which took part in the reaction, we obtain the same result on both sides. Since no loss of matter accompanies any chemical action, this property of a chemical equation always holds good.

Place a piece of phosphorus about the size of a pea in the deflagrating spoon, set it alight and introduce into a large bottle of oxygen. A very brilliant white light is the result and the bottle gets filled *with dense white fumes* which dissolve in the water and give it an *acid taste.* *In this* case, two atoms of phosphorus (P) combine

with five atoms of oxygen (O) to form a white mass called phosphorus oxide (P_2O_5).

A similar experiment may be made with a piece of kindled wood-charcoal, or a bit of charred cork, held in a bottle of oxygen. The chemical change which results, is:—

$$\underset{\text{Carbon.}}{C} + \underset{\text{Oxygen.}}{O_2} = \underset{\text{Carbon Dioxide.}}{CO_2}$$

This compound is a colourless gas which will extinguish a lighted taper plunged into it. Also if a little clear lime water be shaken up with the gas in the bottle it will become milky. We shall have occasion to refer to these reactions later on in this chapter.

Iron burns with violence in oxygen. To prove this, fill a stoppered glass bottle, without a bottom, with oxygen in the usual manner. Then twist a piece of thin iron wire into a spiral and tip one end with sulphur by heating it and immersing it in some flowers of sulphur. A strip of watch spring softened by heating in a flame answers equally well. Fasten the other end of the wire or watch spring into a cork which fits the neck of the bottle. Now kindle the sulphur on the spiral, quickly remove the stopper from the bottle, insert the spiral and press the cork into its place. The sulphur bursts into its characteristic lilac flame and kindles the iron, which burns with great splendour, while white hot drops fall as the iron burns away. These drops may be proved to contain iron and oxygen; three atoms of the former element combine with four atoms of the latter to form Fe_3O_4, that is, oxide of iron. In chemical shorthand—

$$\underset{\text{Iron.}}{Fe_3} + \underset{\text{Oxygen.}}{O_4} = \underset{\text{Oxide of Iron.}}{Fe_3O_4}$$

Potassium, zinc, and numerous other substances burn in oxygen with considerable energy. In fact, every elementary substance, except fluorine, combines with it with more or less activity.

An Oxide is a compound formed by the combination of oxygen with another element.—The experiments described above are all examples of the formation of oxides. They may be summed up thus, and will serve as examples of binary compounds, that is, compounds formed by the union of two elements.

Sulphur and oxygen form sulphur dioxide (SO_2).
Phosphorus and oxygen form phosphorus oxide (P_2O_5).
Carbon and oxygen form carbon dioxide (CO_2).
Iron and oxygen form black iron oxide (Fe_3O_4).

Many elements combine with different proportions of oxygen, and therefore more than one oxide is formed. The following are illustrations of this:—

$$\begin{cases} C + O = CO \text{ (carbonic oxide).} \\ C + O_2 = CO_2 \text{ (carbon dioxide).} \end{cases}$$

$$\begin{cases} S + O_2 = SO_2 \text{ (sulphur dioxide).} \\ 2S + 3O_2 = 2SO_3 \text{ (sulphur trioxide).} \end{cases}$$

Compounds of oxygen are divided into three classes, viz., acid oxides, basic oxides, and neutral oxides. *Acid oxides* are those which when dissolved in water give it an acid taste. Most of the non-metallic elements combine with oxygen to form acid oxides. The formation of acids by the combination of the oxides of sulphur and phosphorus in water has already been indicated. All acids have a sour taste, and turn blue litmus red.

Basic oxides when combined with water produce liquids soapy to the touch and having a peculiar smell. Compounds of this character are termed alkalies. They are formed when potassium or sodium are allowed to combine with the oxygen in water. We then have:—

$$\underset{\text{Potassium Oxide}}{K_2O} + \underset{\text{Water}}{H_2O} = \underset{\text{Caustic Potash}}{2KHO.}$$

$$\underset{\text{Sodium Oxide}}{Na_2O} + \underset{\text{Water}}{H_2O} = \underset{\text{Caustic Soda}}{2NaHO.}$$

Neutral Oxides, such as water (H_2O), and nitrous oxide, or laughing gas (N_2O), possess neither a sour taste, nor a soapy touch, and do not change the colour of litmus.

Salts are compounds formed by the action of acids and alkalies upon one another.—Add a few drops of sulphuric acid (H_2SO_4) to one glass of water, and some caustic soda ($NaHO$) or potash (KHO) to another. The dilute acid will redden blue litmus or a solution of blue litmus dropped into it. It also possesses the sour taste characteristic of acids. The alkali solution will turn red litmus blue, and has the soapy taste before noted. Now slowly add the alkaline liquor tinged blue with litmus to the acid solution reddened with the same substance. The colours of the two liquids will be found gradually to merge into a clear blue, while the acid solution loses its sour taste. Acids and alkalies, therefore, neutralize the effect of each other. On evaporating the clear blue solution, crystals of a salt, known

as potassium sulphate, may be obtained. The change that takes place is symbolised thus:—

Sulphuric Acid.		Caustic Potash.		Potassium Sulphate.		Water.
H_2SO_4	+	$2KHO$	=	K_2SO_4	+	$2H_2O$.

Allotropic forms of elements are those which differ from each other in physical and chemical properties, but nevertheless consist of one single element.—When a stream of electric sparks is passed through a tube containing oxygen, the gas contracts in volume, and acquires several entirely new properties. It possesses a sensible odour; corrodes india-rubber, cork, and many other bodies; bleaches many colouring matters such as indigo, and if brought into contact with mercury, silver, and many other metals, an oxide of the substance is formed. Since no foreign body enters into combination with the oxygen during the electrical action, it can only be concluded that the atoms of oxygen which, under ordinary circumstances, go about in pairs to form a molecule (O_2), are re-arranged so as to form molecules made up of three atoms of oxygen (O_3). This allotropic form of oxygen is called *ozone*. It is condensed to a deep indigo blue liquid by a pressure of 1,900 lbs. per square inch and a temperature of − 105° C. The contraction that takes place when ozone is formed is explained by supposing that three molecules of oxygen form two molecules of ozone, thus:—

Oxgen.		Ozone.
$3O_2$	=	$2O_3$.

All molecules are of the same size; therefore, if it were possible to convert all the oxygen employed into ozone, the volume of the latter gas would only be two-thirds of the former.

Ozone is present in the air to a minute extent, and may be recognised by exposing slips of paper moistened with a solution of potassium iodide and starch, when the paper will acquire a more or less bluish tint, according to the duration of exposure and the quantity of ozone in the air. The effect is most marked on the sea coast when the wind blows in from the sea. The open air of the country generally also gives a marked colour to iodized paper, but in large towns no such change occurs.

HYDROGEN.

Atomic symbol, H. Atomic weight, 1. Weight of one litre, 0·0896 grams. Density (air = 1) = 0·0692.

This gas is very rarely found uncombined on the earth. The exhalations from volcanoes sometimes contain it, and it exists in

small quantities in the breath. Considerable quantities of hydrogen have been driven off from the meteorites which fall upon our earth, by heating them, and it appears to exist in almost all the heavenly bodies. The sun's atmosphere is in a large part composed of highly incandescent hydrogen, nearly all organic compounds contain it, and it is always present in acids.

Preparation of Hydrogen.—Hydrogen is conveniently prepared by the action of dilute sulphuric acid (H_2SO_4) upon zinc (Zn). To perform the experiment fit up a bottle like that illustrated by Fig. 27. Then introduce a few pieces of granulated zinc and pour some water upon it. Add about 25 or 30 drops of sulphuric acid to the water. A brisk effervescence occurs. After this action has continued a couple of minutes pass the end of the delivery tube under a jar or the beehive shelf of the pneumatic trough, and collect the issuing gas. Care should be taken not to make the gas too near to a lighted lamp or burner, or an explosion will occur. If the liquid that remains in the flask after the effervescence has ceased be evaporated, crystals of a salt, termed zinc sulphate, may be obtained. The chemical changes are, therefore, shown in the following equation :—

Fig. 27.

Apparatus for making a small quantity of Hydrogen.

Sulphuric Acid and Zinc form Zinc Sulphate and Hydrogen.

$$\underbrace{H_2SO_4 + Zn}_{\underbrace{98 + 65}_{163}} = \underbrace{ZnSO_4 + H_2}_{\underbrace{161 + 2}_{163}}$$

The equation shows that 65 grams or ounces or lbs., &c., of zinc, when acted on by sulphuric acid, give off 2 grams or lbs., &c., of hydrogen. This proportion holds good for any quantity of zinc. Iron may be used instead of zinc, but the hydrogen thus obtained is not pure, and possesses a peculiarly disagreeable smell.

Hydrogen can also be prepared by decomposing water into its constituent gases, and collecting the latter separately. We have seen that potassium and sodium are able at ordinary temperatures to displace hydrogen from the oxygen, with which it forms water. Red hot iron acts like these two metals. Thus when steam is passed through a red-hot iron tube, the oxygen of the molecules of water (steam) unites with the iron and the hydrogen is set free. The action that occurs is:—

$$\underset{\text{Iron}}{Fe_3} + \underset{\text{Water}}{4H_2O} = \underset{\text{Iron Oxide}}{Fe_3O_4} + \underset{\text{Hydrogen}}{4H_2}$$

It is worthy of remark that copper is without action upon water at any temperature.

Properties of Hydrogen.—This gas is the lightest body in nature. It is 16 times lighter than an equal bulk of oxygen, and $14\frac{1}{2}$ times lighter than air; its specific gravity compared with air is ·0692. Its lightness can be demonstrated by filling soap bubbles with it, and observing them rapidly ascend. Balloons are generally filled with coal gas—a mixture of hydrogen and some of its compounds. If an empty balloon be fitted over the neck of a bottle containing dilute sulphuric acid and zinc, it becomes filled with hydrogen, and if it be closed by means of a piece of thread and set free, it quickly rises in the air. If a jar of hydrogen be held with its mouth downwards, and a lighted taper be brought to it, it will be found that the gas will burn at the mouth with a full blue flame, but that the taper is extinguished if it is thrust up the jar. This is because the hydrogen at the mouth of the jar has a supply of air to unite with. The taper is extinguished when enveloped by the gas because the substances of which it is composed have not the power to combine chemically with the hydrogen, and the hydrogen does not burn inside the jar because there is no oxygen there with which it could combine. It thus appears that *hydrogen is a combustible gas, but will not support combustion.* These terms, however, are entirely relative ones, for it is possible to burn a jet of air or oxygen in an atmosphere of coal gas or hydrogen. In this case the oxygen appears as the combustible, and the hydrogen as the supporter of combustion.

When hydrogen burns in air or in oxygen, or when oxygen is burnt in hydrogen, water is formed. In order to illustrate this *synthesis*, or building up of a compound from the elements which form it, the delivery tube of the bottle in which hydrogen is being

generated, should be fitted with a short piece of wide glass tubing containing calcium chloride or quicklime. This is called a drying tube, and is used in order to ensure the drying of the escaping gas. When the gas has been coming off for some time, and all the air has been carried out of the bottle, light it at the end of the delivery tube, and hold a dry glass vessel or tube over the flame. In a short time the vessel used becomes covered by drops of water. It is found that for every ounce of hydrogen burnt, 9 ounces of water are obtained. The following equation, therefore, expresses the action that occurs, and the proportional weights of the combining elements, and the compound product.

Hydrogen.		Oxygen.		Water.
H_2	+	O	=	H_2O
2	+	16	=	18

Fill a soda water bottle about one-sixth full of water and invert it over the pneumatic trough. Now introduce hydrogen until the bottle is filled with a mixture of the two gases. Slip a glass over the mouth of the bottle and stand it inverted on a table. Wrap a towel or duster around it and hold the mouth to a flame. A loud explosion occurs. We therefore see that hydrogen not only burns quietly in air, or oxygen, but also that hydrogen and air (or oxygen) form an explosive mixture. Experiments show that if a mixture of hydrogen and oxygen is made in the proportion of two to one, and a flame is applied to it, the whole of the gases unite and a few drops of water are produced. Hence water is formed, both when hydrogen burns in air and when it is exploded with air or oxygen.

CARBON.

Atomic symbol, C. Atomic weight, 12. Specific gravity of diamond, 3·3. Specific gravity of graphite, 2·2.

Carbon exists in an uncombined state in nature as *diamond*, and *plumbago* or *graphite* (a substance commonly known as *black-lead*, although it really contains no lead), and *charcoal* or *lampblack*. It occurs in combination with oxygen in the atmosphere as carbon dioxide (CO_2). Chalk is composed of calcium, carbon, and oxygen ($CaCO_3$), and contains about one-eighth its weight of carbon. Carbon is the chief constituent of coal, where it occurs in union with hydrogen, whilst most animal and vegetable matter contains it along with hydrogen, oxygen, and nitrogen. *The presence of carbon* in wood can be proved by putting a

splinter of wood in a test tube and heating it over a flame. Water, hydrogen, oxygen, nitrogen, and some carbon are expelled in the form of vapours, whilst the black substance which remains is the carbon not driven off, and is ordinarily termed *charcoal.* The presence of carbon in sugar can be proved by pouring strong sulphuric acid on to a syrupy solution of it. A black mass, consisting of pure carbon, is left behind. The allotropic forms of carbon are lampblack and charcoal, graphite and diamond. That is to say, the same weight of lampblack, or charcoal, or graphite, or diamond, burnt in oxygen, produces the same weight of carbon dioxide (CO_2). In practice, a certain amount of ash, due to impurities, is left, unless diamond, which may be entirely converted into carbon dioxide, is used. However, by weighing the ash which remains the amount of carbon which united with the oxygen can be found, and experiments show that the weight of the carbon dioxide formed is always equal to the loss of weight which the substance burnt experiences, plus the weight of oxygen utilized. This conclusively demonstrates that diamond, graphite, lampblack, or charcoal, are all forms of one and the same element—carbon. This is well expressed by the equation—

$$\begin{array}{ccccc} \text{Carbon.} & & \text{Oxygen.} & & \text{Carbon dioxide.} \\ C & + & O_2 & = & CO_2 \\ 12 & + & 2\times16 & = & 12+32 \end{array}$$

from which we see that 12 grams, ounces, or lbs., &c., of carbon unite with 32 grams, or ounces, &c., of oxygen to form 44 grams or ounces of carbon dioxide, and so on in proportion for any other quantity.

Diamond.—This, the hardest of all known substances, and the most prized, is a form of carbon found crystallized as octahedra and other regular forms (Fig. 28). When heated in the electric arc, or in oxygen, it first swells up into a black porous mass like coke, and then burns with the formation of carbon dioxide. Its specific gravity is 3·3.

Fig. 28.
A regular octahedron: a typical form of the diamond.

Graphite or Plumbago.—This is another crystalline form of carbon, being often found in hexagonal

(six-sided) plates. It goes ordinarily by the name of blacklead, and is largely employed in the manufacture of drawing pencils. When burnt in oxygen from two to five per cent. of ash, due to the presence of foreign substances, is left. Unlike diamond, graphite is a good conductor of electricity. Its specific gravity is 2·2.

Charcoal is a form of carbon, destitute of crystalline form; that is, it is *amorphous*. Wood charcoal is prepared by heating wood until it ceases to give off gases and vapours. It is considerably used for heating purposes on the continent. Many gases are absorbed by it, and this circumstance makes it capable of floating on water. By driving out the absorbed gases from the pores the charcoal may be made to sink. Its specific gravity is 1·5.

Bone, or animal charcoal, possesses very similar characteristics to wood charcoal, and is obtained in much the same way by heating animal substances until the gases and vapour cease to be evolved. Bone is composed of about 30 per cent. organic matter, and 70 per cent. of such substances as calcic phosphate, magnesium phosphate, calcium carbonate, etc. After it is heated, however, its composition is changed to carbon, 10 per cent., calcic phosphate, 88 per cent., and other salts, 2 per cent. Both wood and animal charcoal possess a purifying power upon noxious and hurtful gases. This is the reason why charcoal in shallow trays is often placed in sick rooms.

Lampblack is another amorphous form of carbon. It is prepared by burning tar or waste oils in closed chambers and collecting the soot on damp blankets. It is used in the manufacture of printers' ink. Indian-ink is a kind of lampblack mixed with gum water and made into cakes and sticks.

Coal is a natural substance containing a large proportion of carbon. We shall have occasion to refer to its constitution more fully later on.

Compounds of Carbon and Oxygen.—Carbon unites with oxygen in two proportions. In one case an atom of carbon (C) combines with an atom of oxygen (O) to form carbonic oxide (CO), and in the other one atom of carbon unites to two of oxygen to form carbon dioxide (CO_2). The latter gas will be considered first.

Preparation of Carbon Dioxide.—As has been previously pointed out, when carbon or any substance containing carbon *is burnt in oxygen*, or in air, carbon dioxide is produced

($C+O_2 = CO_2$). The gas may be more conveniently prepared, however, by placing some fragments of marble, limestone, chalk, oyster shells, or carbonate of soda (washing soda), in such a vessel as was used for the preparation of hydrogen, and pouring some dilute acid, or vinegar, upon it. Any acid poured upon any carbonate liberates carbon dioxide. The gas is 1·5 times as heavy as air, so it may either be collected in the manner illustrated in Fig. 29, or over the pneumatic trough filled with warm water. The production of carbon dioxide in this manner is easily explained. A molecule of marble or chalk consists of one atom of calcium associated with an atom of carbon and three atoms of oxygen ($CaCo_3$). A molecule of hydrochloric acid consists of an atom of hydrogen united to an atom of chlorine (HCl). The action that takes place is therefore exhibited by the equation:—

Fig. 29. Preparation of carbon dioxide.

Marble.		Hydrochloric acid.		Calcium chloride.		Water.		Carbon dioxide.
$CaCO_3$	+	$2HCl$	=	$CaCl_2$	+	H_2O	+	CO_2

That the gas evolved really contains carbon, is proved by filling a small flask with it and heating a small pellet of potassium placed in the flask. The potassium unites with the oxygen and displaces the carbon, which is deposited on the sides of the flask.

Properties of Carbon Dioxide.—This is another colourless and invisible gas. The solubility of the gas in water may be proved by half filling a bottle with water and then introducing the same volume of gas and shaking the two together after corking the bottle. On withdrawing the cork, air may be heard rushing in to fill the space left by the gas absorbed. At ordinary temperature water dissolves its own volume of the gas, that is, a pint of water at 15° C. will dissolve almost exactly a pint of carbon dioxide. This is practically true, whatever the pressure to which the gas is subjected. Thus, if a pint of carbon dioxide be compressed to half a pint, then half a pint of water will dissolve the whole of the gas. This fact is utilised in

the manufacture of ærated waters. Compressed carbon dioxide is forced into water and the solution introduced into bottles in this condition. When the cork is withdrawn, however, the extra pressure is removed and the gas escapes in numerous bubbles. The sparkling appearance of ærated waters, spring waters and wines is due to the presence of this gas. By boiling solutions containing carbon dioxide all the gas can be expelled, for the capability of water to dissolve it decreases as the temperature is increased. With a pressure of about 780 lbs. to the square inch, and a temperature below -31° C., carbon dioxide becomes a colourless, mobile liquid.

If a lighted taper or candle be plunged into a jar of the gas it is at once extinguished. This proves that it *does not support combustion.*

Reference has already been made to the *high specific gravity* of the gas. It is further demonstrated by the facts that it can be poured from one vessel into another like a liquid, and that a candle can be extinguished by letting the gas fall on it.

To perform these experiments, fill a bottle with the gas and show that a lighted taper is extinguished when plunged into it; indeed, it is usual to test the rise of the gas in the jar by observing at what point the taper goes out. Now take an empty jar and show that a lighted taper will burn in it. Gently pour the carbon dioxide from one jar to the other. It will then be found that the taper will not burn in the jar which originally contained air, thus demonstrating that the carbon dioxide has passed into it. By slowly inclining a jar of the gas close to a candle, until it assumes a horizontal position, the candle will be extinguished.

An important *test for carbon dioxide* is its action upon limewater. If a little clear limewater, that is, water in which lime (CaO) has been dissolved, be poured into a jar of carbon dioxide, it at once becomes milky, owing to the formation of calcium carbonate or chalk ($CaCo_3$), which is not soluble in water. The action that occurs is:—

$$\underset{\text{Lime.}}{CaO} + \underset{\text{Carbon Dioxide.}}{CO_2} = \underset{\text{Calcium Carbonate.}}{CaCO_3}$$

If the milky solution be shaken up with another bottle of the gas it again becomes clear, the chalk being converted into another calcium carbonate, which is soluble in water. This is an important fact, because it shows that water containing carbon *dioxide in solution is* capable of dissolving chalk.

If we blow into clear limewater, through a tube open at both ends, in a few minutes it becomes milky. This again is owing to the formation of calcium carbonate. We therefore see that in respiration, or the process of breathing, a quantity of carbon dioxide is given out. By continuing the breathing through the tube the milky solution becomes clear, owing to the conversion of the insoluble calcium carbonate (chalk) into the soluble one.

The production of carbon dioxide during the combustion of carbon, or substances containing carbon, with oxygen, has already been noted.

Fermentation is another source of the gas. This may be proved by warming a bottle containing a little brown sugar, water, and brewer's yeast. A gas is evolved in about an hour, which will put out a light, and render lime-water milky.

Carbonic Oxide.—When carbon dioxide is passed over red-hot carbon contained in an iron tube, it loses part of its oxygen, and is converted into carbon monoxide, or carbonic oxide (CO). The reaction that occurs is :—

$$\underset{\text{Carbon dioxide.}}{CO_2} + \underset{\text{Carbon.}}{C} = \underset{\text{Carbonic oxide.}}{2CO.}$$

This gas burns with a blue flame, and again yields carbon dioxide, thus :—

$$\underset{\text{Carbonic oxide.}}{2CO} + \underset{\text{Oxygen.}}{O_2} = \underset{\text{Carbon dioxide.}}{2CO_2}$$

When an ordinary coal fire burns, carbon dioxide is produced at the lower and outer part of the fire-place. In passing over the red-hot charcoal, the carbon dioxide loses part of its oxygen, and is converted into carbonic oxide, which, on reaching the surface, burns and reproduces carbon dioxide.

Carbonic oxide is a colourless and invisible gas. It is extremely poisonous, and gives a livid hue to the body for some time after death. One of the main causes of the fatal result which attends the inhalation of the fumes of burning charcoal is the presence of carbonic oxide. On the continent, where charcoal is widely used in stoves for fuel, many deaths occur every year from this cause.

The following is a brief descriptive list of all the non-metals arranged in alphabetical order :—

Boron.—Symbol, B. Atomic weight, 10·9. This element is found in nature combined with oxygen and sodium to form borax, and in combination with hydrogen and oxygen as boric acid. It exists both in a crystalline form and as a dark brown amorphous (that is, non-crystalline) powder, insoluble in water.

Bromine.—Symbol, Br. Atomic weight, 79·76. A deep red liquid with a disagreeable smell, and notable as being the only element, except mercury, which is a liquid at ordinary temperatures. It is found in combination with magnesium and other substances in the sea, and in sea-plants and animals. With hydrogen it forms an important binary compound termed hydrobromic acid, or in symbols, HBr.

Carbon.—Symbol, C. Atomic weight, 11·97. An extremely widely diffused element, occurring in at least three forms, viz.: diamond, charcoal, and graphite. This element is fully described in previous pages.

Chlorine.—Symbol, Cl. Atomic weight, 35·37. This is a yellowish-green gas with a suffocating odour. It is rarely found in a free state, but occurs abundantly in nature in combination with sodium (Na), as sea-salt or rock-salt (NaCl), chemically known as sodium chloride. It also occurs in many soils and natural waters, and is constantly present in plants and animals. Chlorine is easily prepared by acting on black oxide of manganese with hydrochloric acid.

Fluorine.—Symbol, F. Atomic weight, 19·06. A colourless gas with a penetrating, disagreeable smell. It is found pretty widely distributed in nature, but never uncombined. Its commonest compound is fluor-spar or calcium fluoride (CaF_2). This substance is found in many soils, in several natural waters, and in the sea. It also occurs in plants, and in the bones of animals. A mineral called cryolite is another source of fluorine, for it is composed of sodium, aluminium, and fluorine, thus united, $6NaFAl_2F_6$. The most important property of this element is its power of corroding or etching glass.

Hydrogen.—Symbol, H. Atomic weight, 1. (Described in preceding pages.)

Iodine. Symbol, I. Atomic weight, 126·54. An indigo-blue crystalline solid, resembling plumbago in lustre. It occurs in combination with sodium or potassium as a constituent of seaweed, and also in certain mineral springs, but is very rarely found in the crust of the earth.

Nitrogen.—Symbol, N. Atomic weight, 14·01. Characterised by its lack of properties. It is a gas without colour, odour, or taste; it neither burns nor supports combustion, and it cannot therefore support life.

About four-fifths of the air which surrounds us consists of *nitrogen in an uncombined* state. It occurs in combination in

coal and some other minerals, and in all plants and animals. Saltpetre, or nitre, is composed of potassium, nitrogen and oxygen thus—KNO_3.

Oxygen.—Symbol, O. Atomic weight, 15·96. A gas having neither colour, taste, nor smell. It is the most widely-diffused element in nature, and exists in a free state as one-fifth the volume of atmospheric air, and combined with hydrogen as eight-ninths the weight of all the water on our globe. It is also an ingredient of nearly all the rocks on the earth. (See previous pages for a fuller description.)

Phosphorus.—Symbol, P. Atomic weight, 30·96. A soft, pale-yellow solid, which may be cut with a knife at ordinary temperatures. An extremely widely-diffused element, rarely found free in nature. Its most important compound is composed of calcium, phosphorus, and oxygen, and is called calcium phosphate ($Ca_3 2PO_4$), which occurs in many rocks. It seems to be essential to the development of animal and vegetable life. Calcium and magnesium phosphates give strength and rigidity to the bones of animals, whilst flesh, blood, milk, etc., all contain phosphorus in some state of combination.

Selenium.—Symbol, Se. Atomic weight, 78·87. A brownish-red, semi-transparent solid. It is a very rare substance, and occurs in nature combined with sulphur and with lead.

Silicon.—Symbol, Si. Atomic weight, 28·0. This important element is obtained in three allotropic forms—(1) as a dull-brown amorphous powder; (2) as hexagonal or six-sided scales similar to crystals of graphite; (3) as brilliant octahedral crystals, hard enough to scratch glass. These forms are analogous to the allotropic modifications of carbon (charcoal, graphite, and diamond), and are often termed amorphous silicon, graphitoidal silicon, and diamond silicon. Silicon never exists uncombined in nature, but its oxide, called *silica*, and symbolised by SiO_2, is the chief constituent of the crust of the earth. It characterises the stony skeleton of our globe just as carbon characterises living matter. Sand, sandstone, and quartz are pure silica, and a multitude of minerals consist mainly of this substance.

Sulphur.—Symbol, S. Atomic weight, 31·98. A lemon-yellow brittle solid at ordinary temperatures. It exists in at least three allotropic forms, respectively represented by the powder called flowers of sulphur, brimstone, or stick sulphur, and crystallised sulphur. The last-named variety is easily obtained by dissolving sulphur in carbon bisulphide, and then evaporating the

liquid. This is the form in which sulphur is found naturally in volcanic districts, where it presents itself in large veins. Sulphur is also abundantly found in combination with many elements: with iron (Fe) it forms the mineral known as iron pyrites (FeS_2), with lead (Pb) it forms another mineral termed galena (PbS), and is united with zinc (Zn) in blende. In combination with oxygen it forms with various metals the ternary compounds known as sulphates. Thus heavy spar is formed of barium, sulphur, and oxygen, in the proportions represented by the formula $BaSO_4$, and is chemically known as barium sulphate. Gypsum is calcium sulphate, and has the formula $CaSO_4$.

Sulphur burns in air or oxygen with a blue flame. The fumes evolve a pungent smell which is known to every one who has struck a brimstone match. The reaction that occurs is—

$$\underset{\text{Sulphur}}{S} + \underset{\text{Oxygen}}{O_2} = \underset{\text{Sulphur Dioxide}}{SO_2}$$

Sulphur dioxide may also be prepared by putting some copper clippings in the bottle used for the preparation of hydrogen, and pouring strong sulphuric acid on them. The gas is about twice as heavy as air, very soluble in water forming an acid solution, highly poisonous, and does not allow a candle to burn in it. It also bleaches vegetable colouring matters. This may be shown by hanging a flower, such as a red rose or bunch of violets, in a jar of the gas, and observing its colour gradually disappear. Another important property of sulphur dioxide is its power of preventing animal substances from putrefying.

Water dissolves about fifty times its volume of sulphur dioxide, the solution thus produced having a very acid taste, and sharing with all acids the property of turning blue litmus red.

Another compound of sulphur and oxygen can be made, namely, sulphur trioxide (SO_3). When this is dissolved in water, sulphuric acid or oil of vitriol is formed. The reaction is thus expressed:—

$$\underset{\text{Water}}{H_2O} + \underset{\text{Sulphur trioxide}}{SO_3} = \underset{\text{Sulphuric acid}}{H_2SO_4}$$

QUESTIONS ON CHAPTER III.

1. Give experiments showing how any two binary compounds can be formed. (1890.)
2. Describe two simple chemical experiments. (1888.)
3. Into what simple compounds can a piece of pure limestone be split up, *and by what means?* (1887.)

4. Name the binary compounds which are united to form a piece of limestone. State how these may be separated from one another, and describe the characters presented by each of them. What elements are present in these binary compounds, and what is the general character of each of these elements? (1880.)

5. How can a mechanical mixture be distinguished from a chemical compound?

6. What are atoms, molecules, and chemical elements?

7. Describe a method by means of which oxygen can be prepared, and state the chief properties of this gas.

8. Explain the meaning of the words acid, base, and salt, as used in chemistry.

9. Describe a mode of preparation, and the chief properties of hydrogen?

10. In what uncombined forms does carbon exist in nature? What are the chief compounds of carbon? Describe their properties.

CHAPTER IV.

WATER—ITS COMPOSITION AND DIFFERENT STATES.

The Three States of Water.—The three physical states, namely, solid, liquid, and gaseous, which matter may assume, are well illustrated by ice, water, and steam. But no chemical alteration takes place during the change from one state to another. A pound of ice furnishes a pound of water, which, if sufficiently raised in temperature, furnishes a pound of steam, and, by proper means, the steam may be condensed into water and then into ice without experiencing the slightest loss of weight or alteration of chemical constitution.

Since ice floats on water it must be lighter, bulk for bulk, than an equal volume of water, that is, its specific gravity must be less than water. Experiments show that the specific gravity of pure ice, compared with water, is 0·918.

Water expands when heated, hence equal volumes of water at different temperatures have not the same weight. This is easily proved by taking equal volumes of hot and cold water, and showing that the latter more than counterbalances the former. When water is converted into steam an enormous *increase of volume occurs*, one cubic inch of water producing 1,696 cubic

inches (that is, nearly a cubic foot) of steam. Equal volumes of air and steam, when at the same temperature and pressure, weigh respectively 1 gram and 0·622 gram. The specific gravity of steam compared with air is therefore 0·622.

Composition of Water.—It is possible to decompose water into its two constituent gases by means of the electric current. To perform this striking experiment at least three Grove's or four Bunsen's cells are necessary. The wires from the battery of cells are joined to the terminal screws of the instrument illustrated in Fig. 30, and called a *voltameter*. Each of these screws is soldered to one end of a short bit of wire, having at the other end a strip of platinum foil. Water, to which a little sulphuric acid has been added, is poured into the basin. Each test tube is now filled with water, and, by placing the thumb over the mouth, and only taking it away under water, each tube may be inverted in this condition over the terminals of platinum foil. If the battery is in working order bubbles of gas will be seen to rise from each strip of platinum and collect in the test tubes. Twice as much gas will come off at the terminal in connection with the zinc plate of the battery as is disengaged at the platinum or carbon plate. When sufficient gas has been collected their properties may be tested. The tube first filled will be found to contain a gas which burns with a pale blue flame, and has all the properties of hydrogen. The remaining tube contains a gas which rekindles a glowing match, and exhibits the properties of oxygen. If the electric current were allowed to flow for a sufficient time all the water would be decomposed into these two

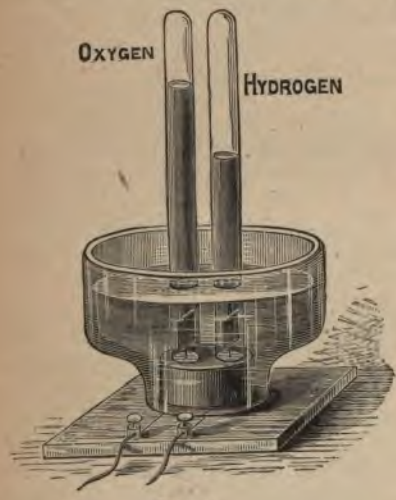


Fig. 30.

A voltameter, for decomposing water into oxygen and hydrogen, by means of an electric current.

gases. It appears, therefore, that water consists of hydrogen and oxygen united, in the proportion of two volumes of the former gas to one of the latter.

The decomposition of water by means of potassium and sodium, and by passing steam over red-hot iron, has been alluded to in the section which deals with the preparation of hydrogen.

The Synthesis of Water.—The formation of water when a mixture of hydrogen and oxygen is exploded by being brought near a flame has already been referred to. In 1766,

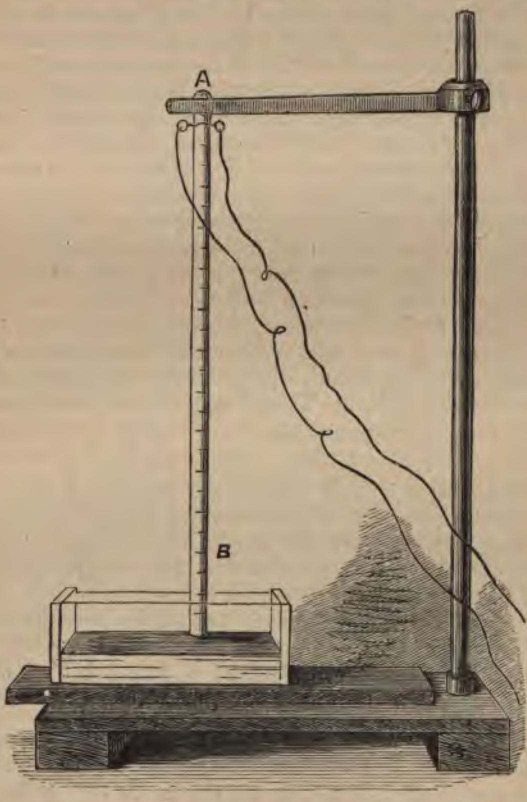


Fig. 31. A Eudiometer for the Synthesis of Water.

Cavendish found that the loudest report was obtained when the hydrogen employed has twice the volume of the oxygen. The most accurate method of forming water by the explosion of its constituents is by means of a eudiometer. This consists of a strong graduated glass tube, open at one end and closed at the other, and having two platinum wires melted through the glass near the top. (Fig. 31.) To perform the experiment, the tube is first filled with mercury. Hydrogen is then introduced, and its volume read off on the graduations of the eudiometer. Oxygen is next caused to enter the tube, and the total volume of the mixed gases read off. The gases can be preserved for any length of time in this condition, but if an electric battery or machine be put in connection with the eudiometer wires, and an electric spark passed between the two platinum terminals inside the tube, a loud explosion occurs, considerable heat is developed, and after the apparatus has cooled down a few drops of water will be seen. If, say, 100 volumes of hydrogen and 80 volumes of oxygen were introduced into the eudiometer, 30 volumes of oxygen would be found in the tube after the explosion. It is thus proved that 100 volumes of hydrogen require 50 volumes of oxygen for their complete combustion. The proportion of the two gases in water is, therefore, as 2 is to 1.

When a stream of hydrogen gas is passed over heated oxide of copper (CuO) the former robs the latter of its oxygen, and the two unite together to form water (H_2O), which may, by proper means, be collected and weighed. The change that occurs is :—

$$\underset{\text{Hydrogen}}{H_2} + \underset{\text{Copper Oxide}}{CuO} = \underset{\text{Water}}{H_2O} + \underset{\text{Copper}}{Cu}.$$

The decrease in weight of the copper oxide is the amount of oxygen absorbed, and the difference of the weight of water formed and the oxygen used gives the weight of hydrogen. The exact weights of the two gases necessary to form water may thus be determined. Experiments show that 16 parts by weight of oxygen always combine with 2 parts by weight of hydrogen to form 18 parts by weight of water. The analysis and synthesis of water, therefore, indicate that its molecule is formed of two atoms of hydrogen combined with one atom of oxygen.

Water as a Typical Chemical Compound.—Whenever or whatever water is analysed, the component gases hydrogen *and oxygen are* always found to occur in the same definite *proportion.* *This,* as has been before remarked, is a charac-

teristic of all chemical compounds. In the case of air, the proportion of oxygen to nitrogen is subject to slight variation, hence air must be a mixture of gases. The constituents of a chemical compound are further distinguished by the differences which exist between their properties and that of the compound itself. Here, again, water is a typical case. The inflammable gas, hydrogen, and the active supporter of combustion, oxygen, combine to form a body which has no properties in common with either. But in the case of air—a mixture—the oxygen and nitrogen do not lose their distinctive properties. The nitrogen merely tones down the active properties of the oxygen, whilst the oxygen may be looked upon as counteracting the negative properties of the nitrogen.

Solvent Properties of Water.—It is commonly known that some substances, *e.g.*, sugar, salt, soda, and alum, are very easily dissolved in water, that is, they are very soluble in it. Others, *e.g.*, chalk, flint, or sand, are practically insoluble. In fact, there is a wide diversity in the amount of different solids which will dissolve in the same quantity of water. As a general rule, hot water will dissolve more of a particular solid than cold. In illustration of this, dissolve some soda in boiling water and allow the solution to cool. As the temperature decreases the amount of soda which the water can hold also decreases, and so some is deposited at the bottom of the vessel. The sugar often seen at the bottom of tea-cups is another example of the same rule. There are, however, a few exceptions to this rule; thus, lime (CaO) is more soluble in cold than in hot water. A solution is said to be *saturated* at a particular temperature when it contains as much of the solid dissolved in it as it will hold at that temperature. At a temperature of 60° F., 1,000 parts by weight of water are capable of dissolving 300 parts by weight of potassium nitrate or nitre. At a higher temperature a greater proportion of nitre to water is necessary to form a saturated solution, whilst a lower temperature requires a lesser proportion of the solid. To demonstrate this make a strong boiling solution of nitre in a test tube, and let it cool to the ordinary temperature of the room (about 60° F.). Nitre will be seen to separate from the solution and sink to the bottom of the test tube. After a short time pour off the clear liquid into another test tube, and hold it in a freezing mixture of ice and salt, or hydrochloric acid and ammonium nitrate. A further separation of the salt occurs for the reason above stated.

In no case, when one body dissolves in another, is there a loss of weight. Thus a pound of sugar or of salt, dissolved in a pound of water, produces a syrupy or briny solution weighing two pounds.

Crystallisation.—If the nitre thrown out of solution in the last experiment be examined it will be found to consist of numerous hexagonal or six-sided prisms. Crystals of common salt may be obtained by making a strong solution of this substance and allowing it to evaporate. They have the form of a cube. In like manner, by evaporating a solution of alum, crystals having an octahedral (eight-faced) form are prepared.

A large number of substances when allowed to form slowly arrange themselves in these regular geometrical forms which are called crystals. Some substances, such as sulphur, crystallise when melted into a liquid and allowed to cool, or when their vapour is condensed, or when they are dissolved in a liquid which is caused slowly to evaporate. The last method is the one employed to obtain crystals of the majority of salts. Substances devoid of crystalline form, *e.g.*, lampblack, are said to be *amorphous*.

Snowflakes consist of crystals of ice arranged so as to form symmetrical figures having six rays or six sides. This hexagonal arrangement can often be detected in snowflakes which have fallen on a dark surface such as the sleeve of a coat.

Water of Crystallisation.—The simple solution of a substance is not of necessity accompanied by chemical action, for it is found that many crystals obtained by the evaporation of the water which contained them do not contain any water. On the other hand, the crystals of numerous salts contain water chemically combined, even though they may appear perfectly dry. The form and the colour of such crystals often vary with the number of molecules of water present. A piece of alum heated in a test tube gives off its water of crystallisation, which condenses on the cooler sides of the tube. At ordinary temperatures a molecule of crystallised alum contains 24 molecules of water, at 100° C. ten molecules are given off, at 120° C. ten more molecules, and at 200° C. the remaining four are driven out of combination. A molecule of zinc sulphate contains seven molecules of water, its true formula being $ZnSO_4 7H_2O$. Six of these molecules are driven off at a temperature of 100° C., and the last one disappears at 240° C. Some substances, such as soda carbonate, give off their water of crystallisation at ordinary temperatures. It is on account of this fact that washing soda gets covered with a layer of a white powdery character and loses its distinctive qualities. Such

substances are said to be *efflorescent*. Some salts, *e.g.*, calcium chloride, act in the opposite manner, that is, they take up moisture and become wet if exposed to the air. These are said to be *deliquescent* bodies.

Magnesium-platinum-cyanide is a good example of a body which changes in colour as it loses its water of crystallisation. At ordinary temperatures its crystals are of a dark salmon-red colour. At 50° C. it parts with one molecule of water and becomes yellow. At 100° C. it loses four molecules and becomes white. At 200° it loses the remaining molecules of water and again becomes yellow. By simply breathing on the white salt the crystals are made to absorb water, and they become pink again. A salt more easily procured is cobalt nitrate. Make a solution of this compound and write some characters with it on a sheet of paper. The writing will be invisible. If, however, the paper be held near to a source of heat the writing plainly appears of a deep blue colour. This is because the cobalt nitrate with which the characters were traced loses its water of crystallisation when it is heated, a blue salt being formed. If the paper be left for a few minutes the blue salt will absorb moisture from the air and pass again into the pink modification.

Soft and Hard Waters.—Some waters—for example, rain-water—easily form a lather with soap, other waters curdle the soap and do not easily produce a lather. The former are called 'soft' waters and the latter 'hard.' Hard waters contain substances dissolved in them which combine with matter in the soap to form the insoluble curd. Soap thus consumed is wasted. Soft waters, on the contrary, do not contain these substances, and so they dissolve the soap and produce a cleansing lather without difficulty.

Temporary and Permanent Hardness of Water.—Water from chalky districts is generally hard in consequence of the calcium carbonate (chalk) dissolved in it. This salt, like other carbonates, is soluble in water containing carbon dioxide, as all natural waters do. When such water is boiled the carbon dioxide is driven off, and the chalk, which the water is no longer capable of dissolving, is deposited as 'fur' or incrustation in the kettle or boiler. Water containing carbonates in solution may therefore be softened by boiling, and so are said to possess *temporary* hardness. Permanently hard waters cannot be softened by boiling. They contain dissolved salts other than carbonates; for instance, calcium *or magnesium* sulphate or nitrate. The addition of sodium

carbonate (washing soda) renders such waters soft and fit for use. A fuller treatment of the substances dissolved in rain, spring, sea, and lake waters will be given in future chapters.

Filtration of Water.—After turbid water has been allowed to stand undisturbed for a short time a sediment will be observed at the bottom of the vessel containing it. This sediment represents the solid matter which was suspended in the water. Water could evidently be roughly separated from the solid particles which it holds in suspension, by causing the sediment to be deposited and then pouring off the clear liquid above it. A more effective method of separating such impurities from water is that of filtration. The filter often used by the chemist consists of a circular piece of unsized paper, which, after folding so as to

Fig. 32. Successive stages in the folding of a filter paper for insertion into a funnel.

make a quarter-circle, is opened and placed in a glass funnel in the manner shown in Fig 32. To illustrate the action of such a filter add water to a mixture of black manganese oxide and sugar, or sand and common salt, and pour it into the filter paper in the funnel. The water passes through clear, leaving the manganese oxide or the sand on the filter paper, but the liquid still tastes sweet or salt according to whether sugar or salt has been dissolved in it. Suspended matter may thus be separated from water by filtration, but not substances in solution. Compressed charcoal blocks and layers of sand and earth act as filters in like manner.

Evaporation of Water.—Dissolved salts can be removed from water by evaporation. This may be proved by putting some of the clear solution from the preceding experiment into a *porcelain* basin and slowly heating it with a spirit flame. The *water passes off* as steam and the dissolved substance is left in

the basin. The same result would be obtained if the solution were allowed slowly to evaporate in the air. The proportion of solid matter dissolved in different waters is always determined by evaporating a known weight of the water under examination and then weighing the salts which remain in the evaporating dish.

Distillation of Water.—In order to obtain water perfectly free from all impurities distillation is employed. The whole process consists in boiling the water to be purified and condensing its vapour. An effective apparatus for distilling liquids is shown in Fig. 33. Water is boiled in a retort, the end of the neck of

Fig. 33. Distillation on a small scale.

which passes into a flask. A wet cloth, or a wet piece of blotting paper, is wrapped round the neck. The steam evolved is thus cooled down and condensed into water and is collected as such in the flask at the bottom. When large quantities of liquid have to be distilled a boiler is used instead of the retort, and the steam is cooled by passing through a long spiral coil of metal tubing kept in cold water.

Maximum Density of Water.—We have remarked in a previous chapter that most substances expand when heated. Water obeys this law generally but not absolutely. If water be cooled it contracts until a temperature of 4° C. (39° F.) is reached. It then begins to expand and continues to expand until it freezes. The point at which water ceases to contract for a decrease of temperature is therefore the point at which water

has a *maximum density*. The late Dr. Joule found that the exact temperature was 3·941° C. If salt be added to water the point of maximum density is lowered. A cubic foot of water at 4° C. expands as it is cooled to the freezing point, and therefore forms more than a cubic foot of ice; hence, bulk for bulk, ice must be lighter than water, and a proof of this is the fact that ice floats on water. Compared with water, the density of ice is 0·92. To prove that water expands, and exerts great force when freezing, fill a small glass bulb with water, seal up the end, and place it in a mixture of ice and salt. The bulb will be burst by the expansion of the water. Iron bombs have been filled with water and cooled down to the freezing point with the same result.

Since water expands when cooled from 4° C. to 0° C., it should contract when heated from 0° C. to 4° C., and this is really the case. To demonstrate the contraction, fit a cork with a narrow glass tube in it to the neck of a flask filled with a mixture of ice and water. As each piece of ice melts it forms a lump of water slightly smaller than itself, hence the height of the liquid in the narrow tube will be observed to sink. Above 4° C. water, like other substances, expands with increase of temperature, and at 100° C. is converted into steam.

It should be borne in mind that ice may be cooled down to temperatures below the freezing point of water (0° C.).

The changes which take place when a piece of ice is heated may be summed up as follows:—

(1) It expands up to 0° C., like other substances.

(2) It melts to form water at 0° C., with decrease of volume.

(3) From 0° to 4° C. the contraction continues.

(4) At 4° C. the point of maximum density occurs.

(5) From 4° to 100° C. water regularly expands.

(6) At 100° C. water is transformed into water-vapour.

(7) Beyond 100° C. water-vapour expands as a gas.

How Water Freezes.—Consider the case of a lake or pond which is being cooled at its surface by cold air. As has been pointed out in the section devoted to convection currents, the chilled particles at the surface get specifically heavier than the water below them; they therefore sink to the bottom and are replaced by lighter particles from beneath. This movement goes on until all the water has been cooled down to 4° C. Further

cooling causes water to expand, and therefore to become specifically lighter. Hence the water particles at the surface, as they are cooled below 4° C., do not descend, but remain at the top, and if they are cooled to 0° C, they are transformed into ice. A film of ice is thus first formed on the surface. This is cooled on one side by the air, and therefore by conduction cools the layer of water beneath, and eventually converts it into ice. The ice thus becomes thickened by the slow process of conduction.

If water did not expand when cooled from 4° to 0° C., the surface particles would continue to get heavier right down to the freezing point, and as the ice was formed it would fall to the bottom instead of remaining at the top. Lakes and ponds would thus soon become solid masses of ice, a large proportion of which would remain unmelted throughout the whole year.

Rapidly moving streams and rivers may have their temperature reduced several degrees below the freezing point of water without any ice forming at the surface. In such cases the water freezes at the points where the motion is least, that is at the bottom. Ice is thus formed on rock surfaces and weeds in the river bed, the formation being known as *ground ice* or *anchor ice*. Its buoyancy is often sufficient to cause it to tear away from the bottom and rise to the surface, with materials from the river bed, to be slowly deposited as the ice to which they are attached is melted.

Latent Heat of Water.—If a pound of water at 80° C. be mixed with a pound of water at 0° C., two pounds of water at 40° C. are obtained. But if one pound of water at 80° C. be mixed with one pound of ice at 0° C., two pounds of water at 0° C. are formed. We therefore see that when ice melts, a large quantity of heat is used up without raising its temperature in the slightest degree. This heat is said to be latent, that is, hidden, because it does not make itself manifest to our sensations. All bodies absorb heat when liquefying and evolve it when solidifying. Thus when sugar or salt is dissolved in water a certain amount of heat is used up, and a handful of nitre thrown into a basin of water lowers its temperature about 10°. When a body is heated part of the energy received increases the motion of its particles and so causes expansion, and another part is spent in overcoming the force of cohesion, that is, in transforming a solid to a liquid or a liquid to vapour.

The heat used up in this manner produces a kind of potential molecular energy which will again appear as heat when a vapour is converted into a liquid or a liquid into a solid. The following experiment is a striking proof of the liberation of latent heat when

a liquid is transformed into a solid. Make a saturated solution of sulphate of sodium at a blood heat. Pour the clear solution into a clean flask and keep it from dust by tying a piece of paper over the neck of the flask. Cool the solution by standing it in water. After an hour or so break the cover of paper. Crystals of sodium sulphate rapidly form, and after a very short time all the liquid is converted into a solid, and the flask feels warm, owing to the latent heat which is given out. It is sometimes necessary to start the crystallisation by dropping a crystal of sodium sulphate into the saturated solution. If it were possible suddenly to convert water into ice, heat would be evolved in precisely the same manner as in the above experiment. A gram of ice requires nearly 80 calories to melt it. Conversely, a gram of water gives out nearly 80 calories when it solidifies.

The latent heats of tin, sulphur, and lead are about 14, 9, and 5, so that these numbers represent the calories absorbed or evolved when a gram of each of these bodies melts or solidifies. As a matter of fact, water has the greatest latent heat of any known substance, that is to say, a pound of ice requires more heat to melt it, or a pound of water evolves more heat in solidifying than any known substance.

Latent Heat of Steam.—If a flask be fitted up as shown in Fig. 15, p. 42, and the water in it boiled, it will be found that the thermometer indicates the same temperature (100° C.) whether it is in the water or just above it. If the boiling is continued long

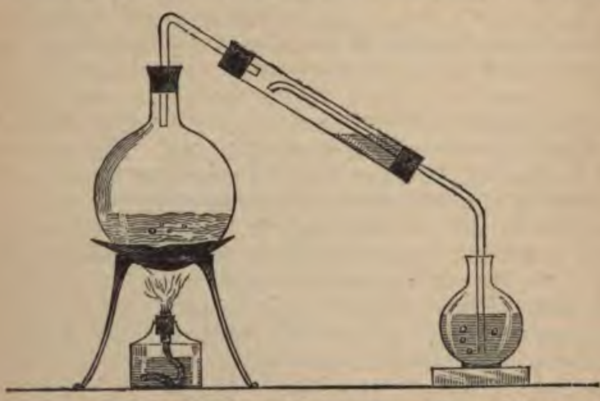


Fig. 34. Method of determining the Latent Heat of Steam.

enough all the water disappears. In this case, similar to that of the experiment on melting ice, the heat of the flame is used up in overcoming the force of cohesion between the particles of liquid, and so in transforming the liquid into a gas or vapour.

It is evident, therefore, that whether water-vapour is produced by boiling or by evaporation, heat must be rendered latent. Conversely, when water-vapour is condensed, heat is given out. To illustrate this, take some water in a flask or beaker and heat it by means of the arrangement shown in Fig. 34. The water will be speedily raised to the boiling point. If the weight of the water at the beginning of the experiment were known the amount of water-vapour which was condensed could be found by weighing the beaker at the end of the experiment; and by noting the temperatures at the beginning and the end, the heat given out by each gram of water-vapour in condensing could be calculated.

An example will make this plain. 100 grams of water at 0° were heated to 100° C. by the addition of 18·6 grams of steam. Hence 1 gram of steam will raise 100 grams of water through $\frac{100}{18.6}$ degrees, that is, from 0° to 5·36°; therefore 1 gram of steam will raise 536 grams of water from 0° to 1° C., that is, the latent heat of steam is 536 calories, a calorie being the amount of heat required to raise 1 gram of water from 0° to 1° C. If 18·6 grams of boiling water were added to 100 grams of water at 0° C. the temperature of the mixture would only be 15·6° C. Steam, then, at 100° C. contains much more heat than water at 100° C. In consequence of this, steam gives a much more severe scald than hot water.

The latent heats of vaporisation of a few substances are as follows:—Steam, 536; alcohol, 264; ether, 91; turpentine, 69; mercury, 62. These values represent the number of calories necessary to convert a gram of each respective substance from the liquid to the gaseous state, or the number of calories evolved when a gram of the vapour is liquefied.

Phenomena Resulting from Latent Heat of Vaporisation.—If a drop of spirit be poured on the hand it quickly disappears, and the sensation of cold is produced. This is because the spirit takes heat from the hand in order to assume the state of vapour. Again, in summer, wet cloths are wrapped round bottles of wine to keep the wine cool, and in hot countries water is often kept in porous earthenware vessels for the same purpose. These facts prove that evaporation cools those bodies in the vicinity

where it is going on—the more rapid the evaporation the greater is the cooling effect.

Importance of the Great Latent Heat of Water and Steam.—Ice is not quickly formed because water has such a large latent heat, that is to say, water has to lose a large amount of heat before it solidifies. Hence a sheet of water generally requires a succession of cold days to rob it of the latent heat which keeps it in a liquid state. Similarly, ice requires a large quantity of heat to transform it into water, and, in consequence, the melting of ice or snow is a very slow process. If this were not the case, then a sudden thaw would quickly melt all the ice and snow that had formed during a frost, and produce enormous quantities of water.

The high latent heat of water-vapour prevents water from evaporating too fast, and from being abruptly and violently precipitated from the air in the form of rain. Again, if water required no latent heat in order to be transformed into the gaseous state, then the change of state would occur the moment it was raised to a temperature of 100° C. When water-vapour is condensed into rain, the latent heat which it contains is given up to the surrounding atmosphere. The heat thus evolved when rain is formed is enormous.

Importance of the Great Specific Heat of Water.—In Chapter II. it was noted that water had the greatest specific heat of all known substances, that is, a pound of water requires more heat to raise its temperature than an equal amount of any other substance. The temperature of water, therefore, is not easily raised or lowered. This is a most important fact. The sea and other sheets of water cannot be made very hot in summer in consequence of the large amount of heat which is necessary to increase their temperature. Neither do they cool quickly during the cold seasons of the year, on account of the large amount of heat that has to be evolved in order to bring about a decrease of temperature. Water surfaces thus modify both the intense heat of summer and the severe cold of winter, that is, they tend to render the climate of a place less hot in summer and less cold in winter. If our oceans and lakes were filled with mercury, which has a low specific heat, instead of water, then whilst the sun was shining they would get extremely hot, but as soon as this source of heat was withdrawn, they would rapidly decrease in temperature.

Influence of Dissolved Salts on the Boiling Point of Water.—Under ordinary conditions water boils at a temperature *of 100° C (212° F.).* By the addition of saline matter the boiling

point is raised. The following table shows the boiling points of a few saline solutions:—

Dissolved Salt	Number of Grams of Salt Dissolved in 100 Grams of Water	Boiling Point of Solution
Sodium Carbonate ...	48·5	100°·6C
Common Salt ...	41·2	108°·4C
Nitre	335·1	115°·9C
Calcium Chloride ...	325·0	179°·5C

Influence of Pressure on the Boiling Point of Water.—The surface particles of any liquid always have a tendency to forsake the body of liquid and pass off as vapour into the surrounding air. This tendency (called vapour tension) is greater in some liquids than in others, and increases with temperature. When water, or any other liquid boils, the tension of its vapour is equal to the pressure upon it. Thus, the average pressure of the atmosphere at sea-level is 15 lbs. per square inch. The vapour tension of water at a temperature of 100° C. is equivalent to this pressure. Under ordinary circumstances, therefore, water boils at a temperature of 100° C. If the pressure on a water surface be 7 lbs. per square inch, then the water begins to boil at 80° C. In illustration of boiling under lessened pressure some hot water may be placed under the receiver of an air pump When the pressure has been sufficiently diminished by pumping out the air, the water will begin to boil even though it is only luke-warm. To further illustrate this important point procure a round-bottomed flask and fit a good sound cork, or india-rubber stopper, to its neck. Boil water in the flask until all the air is expelled, then quickly remove the burner and cork up the flask. Boiling ceases almost immediately; but if the flask is inverted, and a piece of ice placed upon it, the water again begins to boil (Fig. 35). The same result is obtained if the corked flask is immersed in cold water. The explanation of this phenomenon is that the piece of

Fig. 35. Illustration of the effect of pressure on the boiling point of water.

ice placed upon the flask condenses the invisible water-vapour inside, and so diminishes the pressure it exerts on the surface of the hot water.

The pressure of the atmosphere is greatest at sea-level, and diminishes as we ascend. But the temperature at which water boils is less when the pressure is less, hence the temperature of boiling water should diminish as we ascend a mountain. This is actually the case, the rate of diminution being about 1° C. for an ascent of 1,000 feet. The following table shows the temperature of boiling water at a few stations :—

	Height of Station	Boiling point of Water
Salt Lake City, Utah	4,328 feet	95°·8 C.
Summit of Pier, Azores ...	7,613 ,,	92°·5 C.
Lake Moraine	10,357 ,,	90°·1 C.
Pike's Peak, Rocky Mountains .	14,083 ,,	85°·6 C.

QUESTIONS ON CHAPTER IV.

1. State the various forms of water. (1888)

2. State the chief differences in the properties of water in solid, liquid, and gaseous states. Under what conditions are these several states assumed by water? (1886)

3. What chemical elements are found in pure water? What is the nature of those elements? In what proportion do they exist in water, and in what way may these elements be made to combine? (1884)

4. Under what conditions may ice be formed at the bottom of a piece of water? (1884)

5. What chemical elements are present in water? How can water be separated into its elements, and how can these elements be made to re-unite to form water? (1881)

6. Why does ice usually form on the surface of water, and under what circumstances is it occasionally formed at the bottom of a piece of water? (1881)

7. What is meant by the 'water of crystallisation' of a substance? Name a compound which changes in colour as it loses its water of crystallisation.

8. How would you separate suspended matter and dissolved matter from water?

9. What is meant by the latent heats of water and steam?

10. What is the influence of dissolved salts and pressure upon the temperature at which water boils?

CHAPTER V.

METHODS OF MEASURING ANGULAR SPACE AND TIME.

In order to facilitate the study of the astronomical portion of Physiography, it is necessary to state a few elementary geometrical principles on which the methods of measurement depend.

A Plane is a Surface such that if any two points be taken in it the straight line joining them lies entirely in that surface.—A plane surface therefore means an even or level surface—for example, the top of a billiard table or the side of a house; and it is easy to understand that a straight edge would lie upon such a surface in any direction. If, however, the surface be curved in the faintest, there are directions in which the straight line will not touch it all along.

Consider two observers to be looking at a particular object, and let imaginary lines join the eye of each observer to it and to each other; by this means an enormous triangle would be formed. Conceive now a sheet of something to pass through these three points and to extend in all directions; such a sheet would be the plane of the triangle, and the only plane that could be described as long as the observers and the object remained in their same positions. Hence, any plane is completely determined when we know three points through which it must pass. In Astronomy such imaginary planes are constantly used for reference, and objects are said to be so much above or below them according to their position.

A circle is a plane figure contained by one line, which is called the circumference, and is such that all straight lines drawn from a certain point within the figure to the circumference are equal to one another.

This is generally understood, although we may not express our idea of a circle in precisely the same language. It need only be added that any straight line drawn from the centre to the circumference is called a *radius* of the circle, and that a straight line

drawn through the centre and terminated both ways by the circumference is called a *diameter*. The diameter of a circle, therefore, is twice the radius.

If the circumference of any circle be exactly measured, and the diameter also, it will be found that the former is 3·14159 times longer than the latter; hence, if the diameter of a circle be known, its circumference may be found by multiplying it by 3·14159, or, conversely, if the circumference of a circle be known, the diameter may be found by dividing it by 3·14159. This relation between the diameter and circumference of a circle does not terminate in the fifth decimal place as our figures would indicate, but has been carried as far as the seven hundred and sixtieth decimal without terminating. For most practical purposes, however, the relation may be taken as 3·1416, or, expressed in vulgar fractions, $3\frac{1}{7}$, that is $\frac{22}{7}$.

If it be required to find the circumference of a bicycle wheel having a radius of 27 inches, we write—

The diameter of the wheel $= 27 \times 2 = 54$ inches.

Therefore circumference $= 54 \times \frac{22}{7} = 169\frac{5}{7}$ inches $= 12\frac{1}{7}$ feet.

In like manner the circumference of any circle may be found if the diameter or radius be given.

A Sphere or Globe is a solid bounded by a surface, every point of which is at the same distance from a fixed point in the interior called the centre.—Any sphere may be cut in two ways. If the cut be made through the centre the sphere is divided into equal parts, and the circular outline bounding each of the halves is called a *great circle*. All other circles on a sphere are called *small circles*. Now it can be shown by geometry that the superficial area of a hemispherical dome is twice the area of the great circle on which it rests, hence the area of a sphere, which may be looked upon as two domes stuck together, is four times the area of the central section, so that if we cut an orange in half and find that the area of the circular portion is 8 square inches, then the area of the whole orange peel is 4 times $8 = 32$ square inches.

An Ellipse is a plane figure such that the sum of the distances from any point on the circumference to two points within, called the foci of the ellipse, is always the same.—To construct an ellipse fix two pins in a drawing board and tie a loop of thread somewhat longer than the distance between them; place the loop on the pins and stretch it by

means of a pencil. By keeping the pencil in the loop and moving it round, an outline may be drawn similar to that shown in Fig. 36.

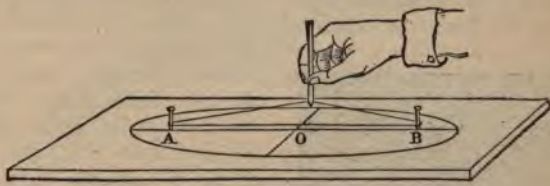


Fig. 36. Construction of an Ellipse.

It is evident from the method of construction that the distance from one of the pins to the other pin around the pencil is always the same—in fact, that the figure satisfies the above definition. The point occupied by each of the pins used in the construction is a focus of the ellipse formed. The longest and the shortest distances across an ellipse are called respectively the *major* and the *minor axes*. The two axes are therefore always at right angles to one another, and the point where they cut is called the centre of the ellipse.

The Eccentricity of an Ellipse is the distance from the centre of the ellipse to either of the foci divided by the length of the semi-major axis. Thus if the greatest distance from the centre to the circumference of an ellipse were 3 inches, and that from the centre to the focus 2 inches, the eccentricity would be $\frac{2}{3}$, or, conversely, if the eccentricity of an ellipse be said to be ·25, this means that the distance between the centre and the focus is ·25, or $\frac{1}{4}$ the length of the semi-major axis. The smaller the eccentricity of an ellipse the more the ellipse approaches the form of a circle—in fact, a circle may be looked upon as an ellipse in which the centre and the foci coincide, that is, an ellipse of no eccentricity.

Measurement of Angles.—In order to measure linear distances some line must be fixed upon as the standard. In England the unit of length is a foot, in France it is a metre, which is equal to about $3\frac{3}{11}$ English feet. We cannot, however, speak of angles as being so many feet or inches long or wide, but must use some angle as the unit, and refer all others to it; so that the measure of any angle is the number of times it contains the

unit angle. Now, all units should be invariable, and it is generally known that a right angle is invariable. The definition given by Euclid is, 'When a straight line standing on another straight line makes the adjacent angles equal to one another, each of the angles is called a right angle.' The straight line which stands on the other is called a perpendicular to it (Fig. 37). Thus the unit of angular measurement could be a right angle, but it possesses the disadvantage of being inconveniently large, so it is divided into 90 equal parts, each of which is called a degree; these again are divided into 60 equal parts called minutes, and the minutes are also divided into 60 equal parts called seconds. A right angle therefore contains 90 degrees, or 5,400 minutes, or 324,000 seconds. It is convenient not to have to write the words degree, minute, and second, so the symbols °, ′, and ″ are used to express them—thus twenty degrees, thirty minutes, six seconds is written 20°, 30′, 6″.

Fig. 37. Right Angles.

A Degree in angular measurement is $\frac{1}{90}$ of a right angle, and since all the angles made by any number of straight lines meeting at one point are together equal to four right angles, the circumference of all circles may be considered to contain 360 degrees.—Let two diameters of a circle be drawn at right angles to one another, then it will be seen that four right angles are encircled by the circumference, and that if each of them be divided into 90 equal parts the whole circumference will be divided into 360 equal parts. (Fig. 38.) The size of the circle is immaterial; if it be divided into 360 equal parts, each of the parts will represent one degree. Take a pair of compasses the legs of which are close together—there is, therefore, no angle contained between them; when opened to the fullest extent the angle is 180°, and when one leg is perpendicular to the other the included angle is 90°. Now, if we took a pair of compasses, and, looking along the legs from the centre, could so delicately open them that one leg pointed to one edge of the moon and the other leg to the opposite edge, we should find that the angle *between the legs would* be about half a degree; and if it were

possible to make a similar experiment with the sun we should find the angle to be 32 minutes, that is, a little more than half a degree. Hence in angular measurement the diameter of the sun and moon is about the same, although the former is incomparably larger than the latter. This is because the moon is

Fig. 38. All circles contain 360 degrees.

much nearer to the earth than the sun. A pair of compasses would not permit these small angles to be measured, but with delicate instruments, specially constructed for such observations, the determination becomes comparatively easy.

The co-ordinates of a Point.—If we observed a particular brick in a wall, and wished to point out in writing which brick it was, we have learnt from common experience that it is necessary to say not only what is the height of the brick in the wall, but what is its distance from some known point in a horizontal direction. (Fig. 39.)

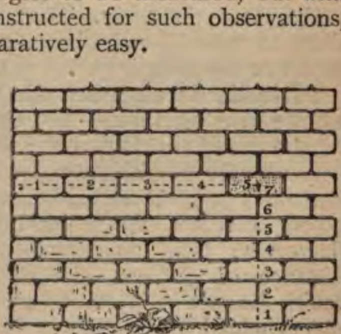


Fig. 39. Co-ordinates of a Point.

Any point in the wall is at once identified if its vertical and horizontal distance be known, and the two distances are called the co-ordinates of that particular point. In like manner the position of a point on the earth is determined by co-ordinates called latitude and longitude, with the difference that they are measured in degrees, minutes, and seconds instead of yards, feet, or inches.

The position of a star or other heavenly body at any time may be stated by co-ordinates termed azimuth and altitude.

The visible Horizon is the boundary line where the sky appears to meet earth or sea.—At sea it is possible to trace the circle of the horizon completely round, but on land the view is usually broken by houses, hills, or trees. We determine whether a surface is horizontal, that is, parallel to the horizon, or not by means of a spirit level.

The Zenith is the point of the sky exactly overhead.—If we attach a ball to a piece of thread, and suspend it, the thread takes up a definite position; in common language, it hangs straight down. The point where such a plumb-line would pierce the sky, if it could be extended upward far enough, is the Zenith. And the point where it would pierce the sky if produced in the opposite direction, that is, the point of the sky directly under foot, is the Nadir. The angular distance from the horizon to the zenith or the nadir is 90°. (Fig. 40).

Fig. 40.

N.W.S.E. is the horizon. Z is the Zenith, *n*, the Nadir. P and P′ are the points where the earth's axis produced cuts the heavens—the celestial poles—and *e* E. *e*′W. is the celestial equator. It will be seen that the celestial equator is about 38° above the horizon. This is its position for the latitude of London.

Altitude is angular distance above the horizon.—The altitude of the zenith is thus 90°; or we may say the *Zenith-distance* of the horizon is 90°. As the altitude of an object increases, the zenith-distance decreases; thus, an altitude of 40° is equivalent to a zenith-distance of 50°, and an altitude of 60° is the same as a zenith-distance of 30°. In all cases the zenith-distance of an object added to its altitude is equal to 90°. The one is the '*complement*' *of* the other.

Azimuth is angular distance from the north or south points of the horizon.—An object half way between the true south and west points of the horizon, that is, having a south-west (S.W.) 'bearing' or 'direction,' has an azimuth of 45°. In like manner the azimuth of any body may be expressed as so many degrees east or west of north or south. *Amplitude* signifies measurements from the east or west points, so that amplitude + azimuth = 90°. It is expressed as so many degrees north or south of east or west. (Fig. 41.)

Fig. 41.
Measurement of azimuth and amplitude.

How the place of a celestial object may be defined by the co-ordinates altitude and azimuth.—If we look at the sky on any fine night, several stars will generally be seen situated at the same height above the horizon, that is, having the same altitude. The place of a particular star, therefore, is not sufficiently defined if we only know its altitude. If a line be imagined drawn from the zenith through a star to the horizon, the arc intersected between the south point and the point where the line touches the horizon is the azimuth of that star. If, therefore, we know the altitude of a star, we know how high above the horizon we have to look for it, and if we know its azimuth we know in what direction to look. For example, to find a star whose altitude is 45°, and azimuth 60° E. of S., we must face towards the point two-thirds of the distance between south and east, E.S.E., and look up half way between the horizon and zenith. An instrument for determining the altitude and azimuth of a body is shown in Fig. 42. The determination of the exact positions of stars depends upon our capability of accurately measuring angles. In the time of Hipparchus (150 B.C.) the place of a star could be determined to within about a third of a degree. Tycho Brahé, who lived in the seventeenth century, determined altitudes and azimuths within a quarter of a degree. Since then several improvements have been made in our methods of pointing, and now it is possible to measure the angular distances of a heavenly body with a probable error of only one thousandth of a second of arc. This accuracy has been partly attained by means of mechanical contrivances, and partly by the introduction of the telescope.

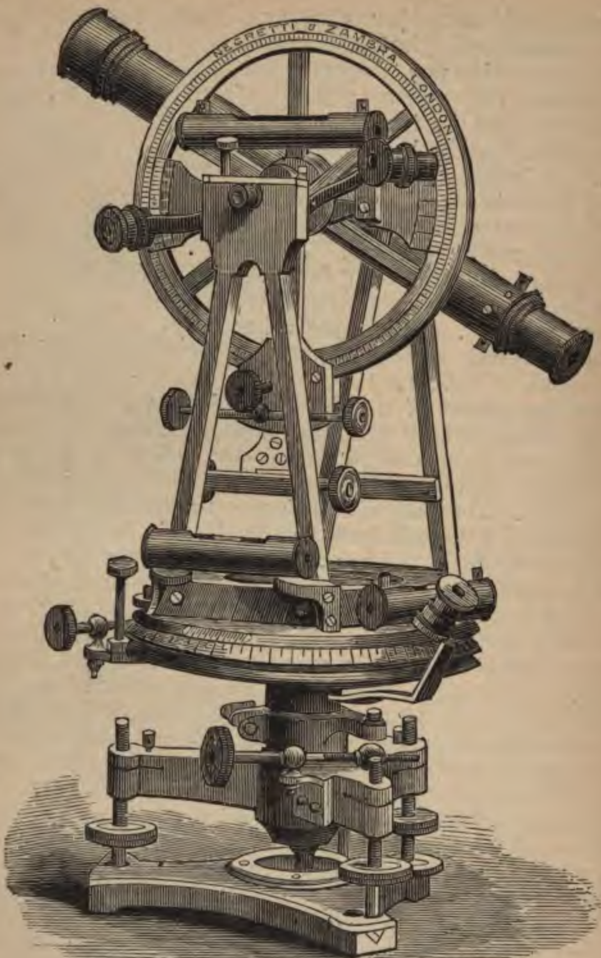


Fig. 42. Instrument for determining Altitude and Azimuth.

The levelling screws at the base are used to set the instrument horizontal. The altitude of any object to which the telescope is directed is given by the *vertical divided circle*, and its azimuth is indicated on the horizontal circle.

The properties of lenses on which the construction of the simple telescope depends.—Get a spectacle glass used by a long-sighted person; it will be found to be thicker in the middle than at the edges, and is known as a double convex lens. Fix the lens so that the light of a candle falls on one of its faces. If a screen of paper is held on the other side of the lens an image of the candle upside down will be received upon it, which will be most sharp and defined, that is, in focus, when the paper screen is at a certain distance from the lens. On moving the candle away from the lens its focussed image advances towards the lens and gets smaller. The same observations could be made with a plano-convex lens, that is, a lens having one face flat and the other convex. If instead of the candle we use for our luminous object any distant body, such as the sun or moon, the focus obtained is termed the *principal focus*. The distance from the lens to the image, in such a case, is the *focal length* of the lens. In general we may say that the more convex a lens is the shorter is its principal focal length. When a schoolboy uses a burning-glass to concentrate the sun's rays on a bit of paper he puts the paper in the principal focus of the lens so as to get the best effect. In such a case all the rays of light which fall upon the lens are parallel, and are concentrated to a point. (Fig. 43.) We may say, therefore, that the principal focus of a lens is the focus of parallel rays. The principal focus of a convex spectacle lens may be distant several feet from the lens. When a lens is placed at a less distance from an object than its principal focus, the rays of light diverge and form an upright magnified image on the same side of the lens as the object. The magnifying property of a convex lens depends upon this fact. We have now shown that a lens will give an image of an object which can be caught upon a screen and has therefore a *real* existence, and is also capable of magnifying an object by forming an unreal or *virtual* image of it, that is, an image which cannot be caught upon a screen. The construction of the simple telescope depends upon these two facts. All that is required is a lens, called an object-

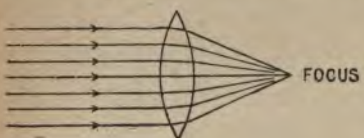


Fig. 43.
The principal focus of a lens.

glass, to give an image, and an eye-piece of much less focal length to magnify it. The paths of the rays are such that the magnified image of the object observed is upside down. The telescope used by Galileo, or an opera-glass, or the small telescopes which may be bought in any toy-shop, do not invert the objects observed. They consist of a convex object-glass to form the real image and a concave lens, that is, a lens thinner in the middle than at the edges, for an eye-piece.

Chromatic Aberration.—If a beam of light fall upon one face of a glass prism it emerges on the opposite face bent towards the base of the prism, and is broken up into the colours of the

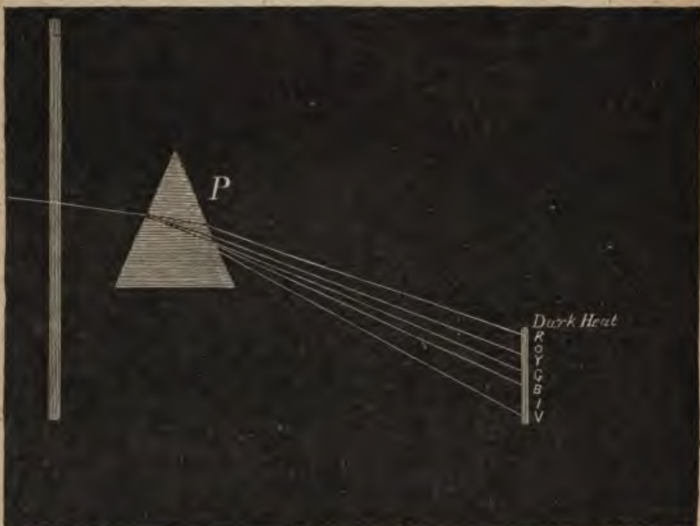


Fig. 44. When a beam of ordinary white light passes through a prism (P), it is broken up into a strip containing all the colours of the rainbow, from red (R) to violet (V).

rainbow. (Fig. 44.) If two prisms are placed with their bases together, and two beams of light be caused to fall upon them, both beams are deviated towards the middle of the combination. (Fig. 45.) It will be seen that the blue colour is nearer the prisms than the red. A convex lens may be considered as made

up of two prisms with their bases together, as in the above example, and a concave lens is similar to two prisms, arranged so that the apex of one touches that of the other. When, therefore, a burning-glass bends the light of the candle or sun to form a small image, it also decomposes the light into its component colours. The result is that the focal length of a lens is less for the blue part of the spectrum than for the red. On a screen

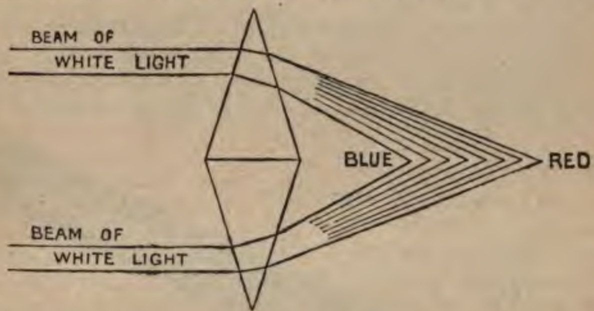


Fig. 45. Deviation and dispersion of beams of light by two prisms.

placed at the distance from the lens at which the blue is in focus the sun's image appears surrounded by a faint red halo, and if the screen be placed at the position of the red focus, the sun's image appears surrounded with a faint blue fringe. At any intermediate position the screen can only be in focus for one colour, and every other colour will form a blurred image upon it. It is thus impossible to get a colourless image of an object with a simple convex lens. This phenomenon is termed *chromatic aberration*.

An Achromatic Lens.—If a beam of light fall upon a prism of flint glass, and one of crown glass of the same size, the distance from the red to the blue part of the spectrum will be found greater in the former than in the latter case. In other words, the dispersive power of flint glass upon light is greater than that of crown glass. A convex lens bends light towards its centre, a concave lens towards its edge. The dispersions of convex and concave lenses are also in opposite directions. By combining a concave lens of flint glass with a crown glass convex lens having a greater deviating power, it is possible to get rid of the dispersive effects of the lenses and yet retain the necessary deviation. We thus get rid of the coloured images referred to in

the preceding section, and form an *achromatic lens.* It is also necessary to have achromatic eye-pieces in good telescopes, microscopes, and other optical instruments. This can be obtained by arranging two lenses at a distance from each other equal to half the sum of their focal lengths; thus, an achromatic eye-piece may be formed by fixing a lens of two inches focal length at a distance of one and a half inches from a lens having a focal length of one inch.

An Achromatic Astronomical Telescope.—All the optical principles given in the last few sections are utilised in the construction of an achromatic astronomical telescope. The object-glass is formed of two lenses, a convex one of

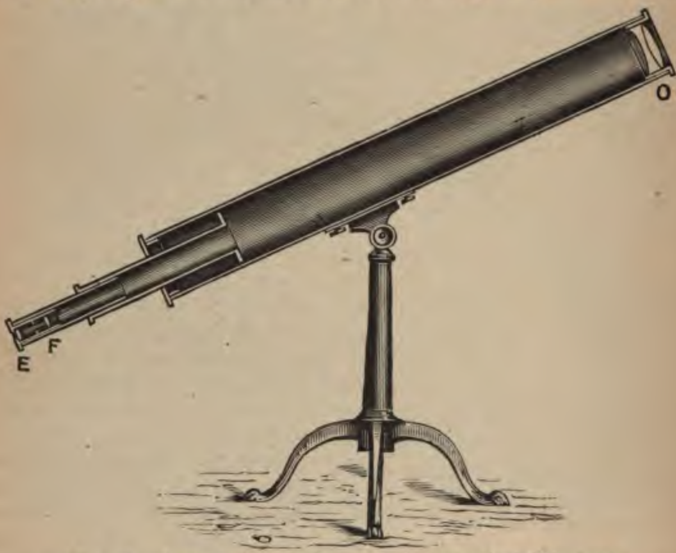


Fig. 46. Section of an Achromatic Astronomical Telescope.
O, an achromatic object-glass; F, the field lens; E, the eye lens; E and F form the achromatic eye-piece.

crown glass, and a concave one of flint glass. This combination acts as a single convex lens of long focal length, and produces an inverted real image of an object at its focus. In order to magnify the image a convex lens may be used, or a *compound achromatic* one. (Fig. 46.) In either case the object

observed appears upside down, but for astronomical observations this is of no consequence. The tube of the telescope serves to keep out extraneous light and fix the lenses at their proper distance apart.

The Meridian of any place on the surface of the earth is the line which passes from the North Pole to the South Pole through that place.—Every morning the sun rises in the east, gets higher and higher in the sky, and at noon reaches its highest point, then it begins to sink towards the west, and finally disappears beneath the western horizon. In our hemisphere when the sun reaches its highest point it is exactly in the south; indeed, it is said to 'south,' and the shadows of all objects have then a true north and south direction. Hence, to set out a north and south line by means of the sun, a rod should be stuck in the ground, and a line drawn in the direction of its shortest shadow on any day. Another way is to draw a line in the direction of the shadow of the rod before mid-day, and another line when the shadow has the same length in the afternoon. (Fig. 47.) The line bisecting the angle between these two lines points to the North and South Poles of the earth, so that if the extremities of such a line could be produced far enough they would pass through the poles. We call this line a *meridian*. A peeled orange represents a globe having about ten meridians marked upon it.

Fig. 47. Method of finding true north and south.

The Transit Instrument.—When an object crosses the north and south line, or meridian, it is said to pass the meridian, or, shortly, to *transit*. The observations of the times at which the heavenly bodies transit are of fundamental importance in the measurement of time. The interval of time which elapses between two successive southings or transits of the sun is called a *solar day*, and is divided into 24 hours. We shall see later on that this interval varies throughout the year. The stars can also be observed to rise in the east, to transit when they reach their highest point, and to set in the west; and if a star be observed to transit one night and to transit again the following night, the interval of time that elapses between these successive transits is called a *sidereal or star day*, and is 23 hours, 56 minutes, 4 seconds long. This interval is always the same. The causes

of the difference of time between the solar and sidereal day are given in Chapter VIII.

An instrument for making transit observations is shown in Fig. 48. It simply consists of a telescope attached to an axle which turns on U- or V-shaped bearings. These bearings are made exactly horizontal by means of a spirit-level of sufficient length to stride from one bearing to the other. The axis has also to be adjusted so that it points East and West, in which case the telescope will point true North and South. On looking through the instrument several vertical wires will be seen, and one horizontal one. The central vertical wire should intersect with the axis of the telescope, and therefore represent the exact position of the meridian. If the adjustments have been correctly made, the interval of time between two successive transits of the same star will be exactly 23 hours, 56 minutes, 4 seconds. It follows, therefore, that if we know at what time a particular star or other celestial object ought to pass our meridian, and we observe the time at which the body actually does transit, we have a means of correcting or regulating our clocks and watches with the greatest precision. A rough arrangement for observing transits may be made by fixing a thin rod or sight in a true North and South line, and suspending a weight by a thread at a short distance in front of it in the same direction. By looking along the sight stars can be observed to pass behind the wire, that is, to transit.

Fig. 48. A Transit Instrument.

The Pendulum.—Make a simple pendulum by attaching a bullet or a piece of lead to a thread. Suspend the pendulum and show that the time required to make, say, 25 large oscillations is the same as the time required to make the same number of small ones. Now shorten the length of the thread. The pendulum oscillates faster; and it can be proved that the time of oscillation is *proportional to the square root* of the length of the pendulum, whatever

weight or whatever substance is used for the pendulum bob. Hence, in order to double or treble the time of oscillation, the length of the pendulum must be increased four or nine times. If the distance from the point of suspension to the centre of the bob is 39·139 inches, the pendulum will swing, at Greenwich, from right to left or left to right in one second. We say at Greenwich, because observations show that the length of the seconds pendulum differs in different places. The reason of this will be understood if it be remembered that the intensity of gravity, which causes a pendulum to swing, varies over the surface of the earth, and is greatest at the poles and least at the equator.

To sum up these laws, we have:

(1.) The time of oscillation of a pendulum is independent of the extent of swing.

(2.) The time of oscillation is independent of the weight or nature of the pendulum bob.

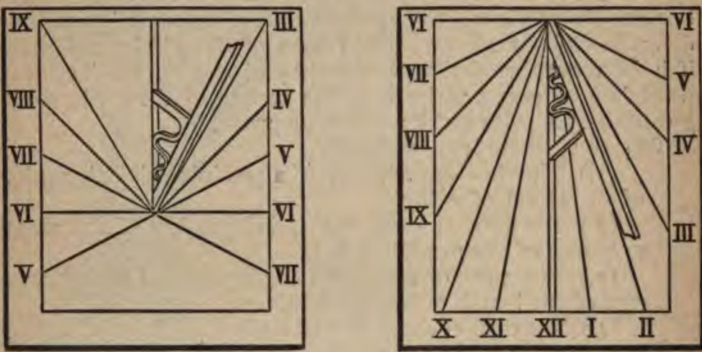
(3.) The time of oscillation is proportional to the square root of the length of the pendulum.

(4.) The time of oscillation of a given pendulum decreases in passing from the equator to the poles.

Clocks and watches are mechanical arrangements for measuring the flow of time. Some source of energy, such as a suspended weight or a wound-up spring, gives motion to a pendulum or a balance wheel, which motion, by a proper train of wheels and cogs, is communicated to the hands of the clock or watch. The motion of the hands is so regulated that the interval of time which we call an hour, indicated by them, is a twenty-fourth part of the average length of the day.

Sun-Dials.—The changing direction of the shadows of all objects as the sun crosses the sky is so manifest a phenomenon that the method of measuring time by means of the sun-dial is of great antiquity. The principal parts of a sun-dial are a projecting rod parallel to the earth's axis and called a *style*, and a plate of some kind called a *dial* to receive its shadow (Fig. 49). When the sun rises in the east the shadow falls to the west; with the movement of our luminary to the south the shadow passes towards the north, reaches its shortest length, and is due north at mid-day when the sun is highest. It then passes eastward until sunset. At night the position of the stars relative to objects on the earth may be roughly used for the same purpose. Thus, by properly marking lines on the dial-plate, the direction of the shadow of the style may be used to indicate the time of day. Since the style

must be parallel to the earth's axis, that is, must point in one direction to the north celestial pole, the position of which is approximately indicated by the pole star, the angle which it makes with the dial depends upon the latitude. In the case of a horizontal sun-dial the angle which the style makes with the dial



To face the North. To face the South.

Fig. 49. Sun Dials.

should be equal to the latitude of the place where it is used; hence, in London the inclination is $51\frac{1}{2}°$. At the poles, therefore, the style would have to be perpendicular to the dial. The inclination of the style in vertical sun-dials is equal to the latitude of the place of observation subtracted from 90°. Thus, in London the inclination is $90° - 51\frac{1}{2}°$, that is $38\frac{1}{2}°$.

QUESTIONS ON CHAPTER V.

1. Describe shortly the construction of an achromatic astronomical telescope (1889).

2. Describe the construction and use of the transit instrument.

3 Define *zenith*, *nadir*, *altitude*, *azimuth*, and *amplitude*.

4. Explain the meaning of the following terms used in connection with lenses:—*principal focus*, *focal length*, *real* and *virtual* images, *chromatic abberration*.

5. State the circumstances which affect the time of oscillation of a pendulum.

6. How would you construct a sundial and use it for the measurement of time?

CHAPTER VI.

THE EARTH AND ITS MOVEMENTS.

THE first opinion held by primitive mankind with respect to the form of the surface of the earth was that it was flat. More critical glances at natural phenomena, however, soon demonstrated that this was not the case, and that the earth is globular in form, indeed we find that this fact was taught by Thales six hundred years before the commencement of our era. That the earth is not flat is proved by the following simple facts :—

(1) The highest points of approaching objects are the first to become visible, and, in the case of receding objects, the last to sink beneath the horizon.— This fact may be gathered from observations of vessels approaching to, and receding from, any sea shore. To an observer on the margin of the sea, a ship approaching the shore appears to rise out of the water. In the distance only the top-masts are seen, then the rigging becomes visible, and lastly the hull. If the ship is moving away from the shore, first the hull disappears, and the vessel is said to be 'hull down,' then the

Fig. 50. Apparent rising of a ship above the horizon caused by the curvature of the earth's surface.

rigging sinks out of sight, and finally, by means of a telescope, the highest parts of the masts can be observed slowly to sink beneath the horizon. Such appearances as these could evidently not happen if the surface of the earth were flat and the disappearances were due to an increase of distance, for then the

thin masts would be the first to fade out of sight, and the thick hull would remain visible for the longest time. It is evident, however, that these phenomena would occur precisely as described if the surface of the earth be curved. (Fig. 50.) Similarly, when a ship approaches the shore, an observer on it first sees the mountain-tops, then the hills, and, finally, the low ground appears. But this does not prove that the earth is globular like an orange, for if the earth were egg-shaped the above-described phenomena could be observed.

(2) If three poles of exactly the same height be placed in a line, the middle one always appears higher than the two outer ones.—Let three poles be fixed in line with their tops cut off at exactly the same height above some level surface, such as the surface of a canal. Then if a telescope is sighted along the first to the third pole, the top of the middle pole will appear above the line joining the tops of the two outer ones. The cause of this is the curvature of the earth's surface, and if the experiment could be repeated in various parts of the earth, and it was found that the curvature was everywhere the same, this would prove that the earth's form is globular, and an approximate determination of its size could be obtained. It is found that the middle pole rises eight inches above the line joining the two outer ones when the distance between each pole is a mile; and it can be easily proved that in order to describe a circle having a curvature of eight inches in a mile the two ends of a pair of compasses would require to be separated by 3,960 miles. This, then, is the length of the radius of the earth, and the diameter is therefore, approximately, 7,920 miles.

Circumnavigation in an easterly and westerly direction does not prove the earth to be globular.—In A.D. 1519 the Portuguese Fernando de Magelhaens, starting from Seville, in Spain, sailed through the Straits at the end of South America, named after him, to the Pacific archipelago, and thence his ship returned round the Cape of Good Hope to Spain. Since then the earth has been circumnavigated a great many times, and it is a common occurrence for a ship to leave England and by steering westward all the voyage to arrive in England again without retracing an inch of her way. Similarly, we can journey round the globe, sometimes travelling on land and sometimes on the sea, but eventually return to the starting point without at all turning back *on our course.* This would appear to be a certain proof that the

earth's surface is curved, nevertheless it has been pointed out that circumnavigation would be possible if the earth had a flat surface with the north magnetic pole at its centre. A compass needle would then always point to the centre of the surface, and so a ship might sail due east or west, as indicated by the compass, and eventually return to the same point by describing a circle (Fig. 51).

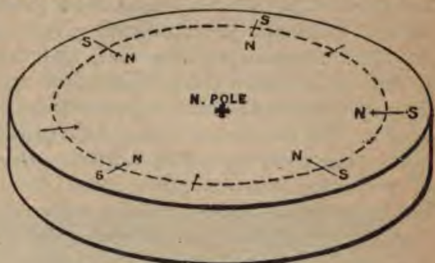


Fig. 51. Proof that circumnavigation would be possible if the earth were flat.

We will now state some facts which prove that the form of the earth is approximately globular or spherical like a ball.

(1) **The area embraced by the horizon is always circular.**—If a person stand on a vast plain, or on the deck of a ship at sea, the plain or the sea is seen to extend until earth and sky appear to meet in a line; this line limits the vision in every direction, and is called his horizon. Now it is found that whether observations be made from the deck or the mast head of a ship, the

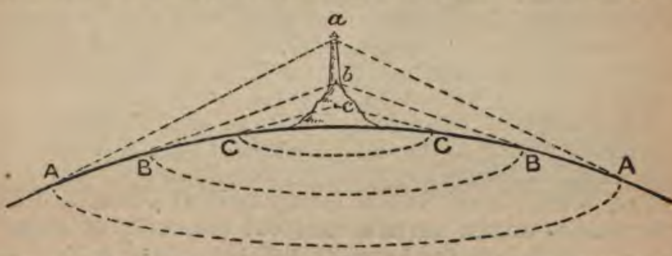


Fig. 52. Increase of the distance of the visible horizon with increase of height above sea-level.

plain stretched out beneath appears bounded by a circular outline, with only this difference, that the greater the height above the surface the larger the circle appears. An ordinary observer, whose eyes are six feet above sea level, has his horizon three miles off, at ten and a half feet this is extended to four miles, and from the top of

a lighthouse ninety-six feet high the horizon line is twelve miles off. But the line is always a circle, and this is a proof positive that the earth is globular in shape, for a globe is the only body which viewed from any point outside gives a circular outline (Fig. 52). As an illustration of this fact, the case of a fly, or any small insect, on or above the surface of an orange might be mentioned. The fly's vision will always be bounded by a circle of which it is the centre. For the reason that a circle can only have one centre, every person must have his own horizon—that is, must be the centre of a circular area extending round him on all sides, which area he, so to speak, carries with him wherever he goes. In general, however, an observer is not so situated as to be able to see the horizon in every direction.

(2) **The shadow of the earth, as seen upon the moon during a lunar eclipse, is always circular.**—It occasionally happens that at the time of full moon part or the whole of its disc becomes obscured. A dark shadow, having a circular outline, first appears on the eastern edge, slowly passes over, sometimes blotting out entirely the light of our satellite, and then leaves at the western edge. These appearances are called eclipses of the moon. The fact that such eclipses always occur at full moon was early noticed, and the idea that the cause of an eclipse was the moon passing into a shadow cast by the earth suggested itself, and was understood by the earliest observers. Now whenever these eclipses occur, the earth's shadow always appears circular, which demonstrates conclusively that the earth is a globe, for this is the only shape which will always throw such a shadow.

It is now necessary to give a few definitions and general considerations relating to the determination of the exact size and shape of the earth.

The North and South Geographical Poles are the extremities of the earth's shortest diameter or axis.—We have seen from the foregoing that the general form of the earth is globular. It is not, however, a perfect globe, but resembles an orange inasmuch as it is somewhat flattened at the top and bottom, and hence there is one diameter which is shorter than any other. The imaginary line passing through the earth's centre and piercing the flattened regions—that is, the earth's shortest diameter—is called the *Axis*, and the extremities of the line are called respectively the *North and South Geographical Poles.*

The Celestial Poles are the points where the earth's axis produced meets the heavens.—Imagine the earth floating in space, and ourselves viewing it a few million miles away. Let the axis be produced until it meets the heavens. The points where this axis, produced both ways, appears to cut the heavens are called the *North and South Celestial Poles*. Near the point where the northern extremity of the axis meets the sky, there happens at the present time to be a bright star, which is therefore known as the Pole Star; that is to say, an

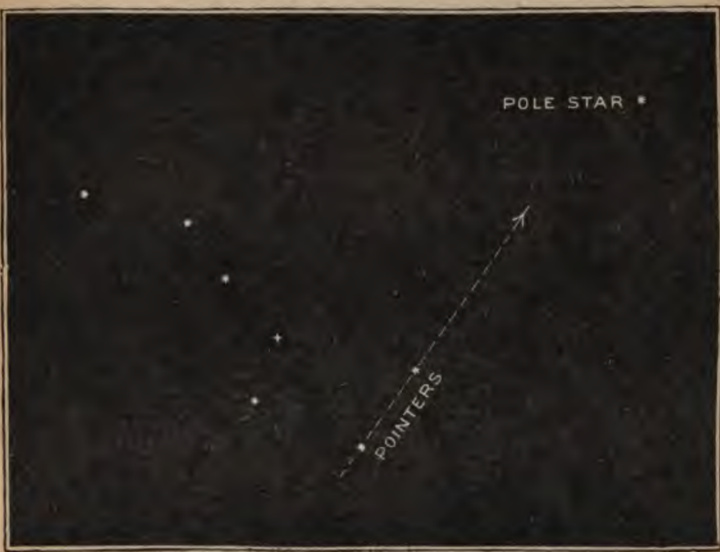


Fig. 53. The constellation of the Plough used to find the Pole Star or North Star.

observer at the north pole would see the pole star right overhead. No bright star, however, marks the position of the south celestial pole.

The conspicuous group of stars shown in Fig. 53 is familiar to most people. Two stars of the group, called the Pointers, are almost in a line with the Pole star. It is a mistake to suppose that this star is always due north. The north celestial pole is the

north point in the heavens, and a telescope pointed towards this point has a true north and south direction. But the Pole star describes a small circle around the celestial pole. It is only due north twice in twenty-four hours, when it is exactly above or below the celestial pole. At other times it is something less than $1\frac{1}{4}°$ east or west of true north. (*See* Answers at end of book.)

The Celestial and the Geographical Equators are great circles half way between the two poles, and therefore 90° from each.—In other words, the *earth's equator* is an imaginary line running around the earth, midway between the north and south poles; hence, any place which is at the same distance from the north pole as it is from the south pole is on the equator. Similarly, the *Celestial Equator* is the great circle equi-distant from the north and south celestial poles, and hence a star exactly overhead to an observer on the earth's equator is on the celestial equator. Our globe and the heavens are thus divided into two portions by the equator, one portion containing the north pole, and the other portion containing the south pole. These two halves of a globe are therefore respectively called the northern and the southern hemisphere.

Geographical Latitude is angular distance North or South of the earth's equator.—Circles are conceived to be drawn around the earth parallel to the equator, and since the distance from the equator to either pole is a quarter of a circle or 90°, ninety of these parallels may be supposed to be drawn upon the northern and ninety upon the southern hemisphere. Such circular lines are called *parallels of latitude*, and are counted northward or southward from the equator to the poles; thus, a place on the equator is in latitude 0°, abbreviated, lat. 0°, London is in $51\frac{1}{2}°$ northern latitude, or lat. $51\frac{1}{2}°$ N., and the latitudes of the poles are respectively 90° North and 90° South. We thus speak of places as being in *high latitudes* when they are situated near either pole, and in *low latitudes* when they are near the equator. Intervening places are said to be in *middle latitudes*.

Declination is angular distance North or South of the celestial equator.—The heavens, like the earth, are conceived to be traversed by lines drawn parallel to the celestial equator. But they are called *Parallels of Declination*. All stars exactly over the earth's equator, that is, on the celestial equator, are in declination 0°, all stars south of the celestial equator are *in south declination*, and stars north of it have north declination.

The declination of the Pole star at the present time is about $88\frac{3}{4}°$ North, that is, $1\frac{1}{4}°$ from the north celestial pole.

The Latitude of any place is equal to the altitude of the celestial pole at that place.—We have seen that the visible horizon only extends a few miles from an observer on the earth's surface. Now consider what an observer at the north pole sees of the heavens: the pole star will be nearly vertically overhead, that is, almost in the zenith, and but for the fact that the faint light of stars is blotted out by our atmosphere he would see all the stars in the northern hemisphere. Roughly speaking, half the stars in the heavens could be observed at one time, and the stars on the celestial equator would just be visible where earth and sky appear to meet. It would appear at first sight that since an observer at either pole can see half the celestial sphere he ought to be able to see half the surface of the earth. We know, however, that this is not the case; and the reason why so much of the celestial sphere is seen is because the earth is but a point when compared with the immensity of space. If observations be made at the equator, the pole star appears on the horizon, as is made manifest in Fig. 54.

Fig. 54. Increase of the altitude of the Pole Star with increase of distance from the equator.

That is to say, an observer in latitude 0° sees the pole star on his horizon, and, since the altitude of a body means its height above the horizon, a point on the horizon has an altitude of 0°. Let the observer travel in a direct line towards the north pole; the pole star would appear to rise above the horizon until, when the north geographical pole was reached, it would appear overhead—that is, to an observer in latitude 90° the pole star has an altitude of nearly 90°, hence in moving from latitude 0° to latitude 90° the pole star also moves from an altitude 0° to an altitude of nearly 90°, half way between the equator and the north pole, that is, in latitude 45° the pole star would appear to have an altitude of 45°, and so on for any other point. Thus we arrive at the important law that the altitude of the pole seen from any place on the earth's surface is equal to the latitude of that place. It is by the use of this law that travellers on sea or land can determine the latitude they are in simply by an observation of the pole star. Since, however, this star is not visible south of the equator, nor in the daytime, it is more convenient to use the sun for the purpose of determining latitude.

The Length of a Degree of Latitude is the distance which it is necessary to travel in a north and south line, in order to produce a difference of 1° in the altitude of the pole.—It now remains to show how by the application of the foregoing principles the exact size and shape of the earth have been determined. Let an observer at the equator, after noting the pole star on the horizon, travel in a direct north and south line until it has risen 1° above the horizon, that is, until the altitude of the star is 1°, and let the distance necessary to make this difference of 1° in altitude be measured. Similarly, the distance necessary to travel in order to produce a difference of 1° in the altitude of the pole might be measured at any point. Now it is found that anywhere on the earth's surface the distance necessary to travel in a direct north and south line, to produce a difference of 1° in the altitude of the pole, is nearly the same, and therefore the earth must be nearly spherical in a north and south direction. If it were cylindrical in shape then the lines drawn from any point on the curved surface to a star would all be parallel, and hence there could be no alteration in the altitude of a star as an observer travelled up and down the cylinder. From accurate measurements made in different parts of the earth, and from observations of the change in altitude of the

celestial pole, it has been found that the average distance required to travel is about 69 miles; this then is the average length of a degree on the earth's surface, and since there are 360° in every circle, the circumference of the earth in a north and south direction is 69 × 360, or 24,840 miles, and its diameter is therefore about 7,904 miles. These estimations of the lengths of degrees of latitude are called measurements of *arcs of meridian*, because they are made in a true north and south line, or in the meridian.

Degrees of Latitude increase in length in passing from the equator to the poles.—Accurate determinations have shown that the length of a degree of latitude is greatest at the poles, and diminishes as the equator is approached. The following table gives the length of a degree in different latitudes:—

Latitude.	Length of one degree.	Latitude.	Length of one degree.
0°	68·69 miles	50°	69·10 miles
10	68·70 ,,	60	69·21 ,,
20	68·77 ,,	70	69·32 ,,
30	68·88 ,,	80	69·38 ,,
40	69·00 ,,	90	69·39 ,,
45	69·05 ,,		

If the earth were a true sphere then the length of a degree of latitude would always be the same. It is therefore not exactly spherical in form.

Proof that the earth is an oblate spheroid.—The reason for the above slight variation is that the earth is flattened at the poles and bulged out at the equator, being very similar in shape to an orange, or an oblate spheroid. If the earth were flat, then however far we travelled we could never change the altitude of the pole, that is, we could never traverse a degree of latitude. We might infer, therefore, that the surface of the earth is most flat where the degrees of latitude have the greatest length, that is, near the poles. Again, a plumb-line points in one direction to the earth's centre, and in the other to the zenith. At the equator it is necessary to pass over 68·69 miles along the same meridian in order to produce a difference of one degree in the zenith distance of a star, that is, in order that the plumb-lines at the two places may be inclined to each other at an angle of one degree. Near the poles it is necessary to pass over 69·39 miles to produce the same angle between two

plumb-lines. The earth's surface is therefore more curved at the equator than at the poles (Fig. 55). This being so, the polar diameter of the earth, that is, the line joining the north and

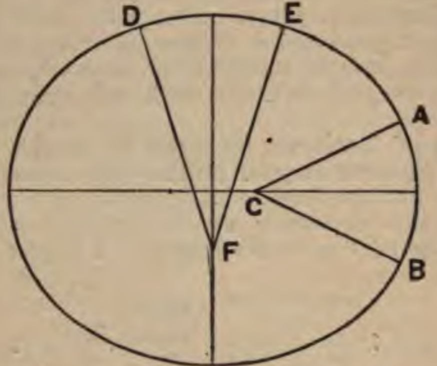


Fig. 55. Proof that the earth is flattened at the poles. The zeniths at A and B meet at C, a certain distance from the surface. The distance DE is equal to AB, but the angle DFE is less than ACB, so F is more removed from the surface than C, that is, DE is part of a larger circle than AB.

south poles, must be shorter than a line joining a point on the equator through the earth's centre to a point opposite. The two diameters differ in length by about 26 miles, one exact determination being as follows :—

Equatorial diameter	7,926 miles.
Polar ,,	7,900 ,,

The Shape of the Earth can be determined by Pendulum Observations.—If the earth were a sphere, and all points equi-distant from the centre had the same density, then the force of gravity would be the same at all points on its surface. But observations show that the force of gravity is greater at the poles than at the equator by about $\frac{1}{190}$th part, that is to say, a piece of gold which weighs 190 ounces in a spring balance at the equator would weigh 191 ounces at the poles. The force of gravity causes a pendulum to swing. If, therefore, the force were constant all over the earth, a pendulum of a given length would perform an oscillation in the same time wherever it was taken. Accurate observations demonstrate that this uniformity does not exist, and that the

length of a pendulum necessary to beat seconds increases from the equator to the poles. As a matter of fact, a pendulum 39 inches long that beats seconds at the equator would have to be lengthened $\frac{1}{5}$ of an inch to beat seconds at the poles. From the results obtained in different latitudes the amount of flattening has been calculated. Such observations, however, only determine the shape of the earth, and give no information respecting its size.

The Apparent Daily Movements of the Heavenly Bodies.—From casual observations it would appear that the earth is immovable and that above it there is a large hollow globe in which the sun and stars are fixed, which imaginary globe turns slowly round the earth from east to west and causes the appearance of day and night; hence, when man argued that all the heavenly bodies were small and insignificant in comparison with the earth, and considered the world as an object by the side of which all others were unimportant, he concluded that it was immovable in the centre of the universe, and that all the heavenly bodies revolved round it. It can now, however, be shown that the moon is much nearer to the earth than the sun, that the sun is beyond comparison nearer to us than the nearest fixed star, and that some stars are infinitely more distant than others; hence it is impossible to imagine that all these bodies are moving around our little earth, keeping their relative places unchanged. And since it is true that the appearance will be practically the same whether we consider that the earth is at rest and the heavens revolve round it, or that the heavens are fixed and the earth rotates on its axis like a top, it is easier to accept the latter supposition that the earth rotates on its axis in about 24 hours than it is to imagine that the whole universe revolves round the earth in the same time.

The daily motion of the heavens from east to west is only an apparent motion, and is caused by a daily rotation of the earth from west to east on its shortest diameter.—The honour of first proving to the world the true theory of the celestial motions belongs almost exclusively to a monk named Copernicus, who was born at Thorn, in Prussia, in 1473. The Copernican system was not published until 1543, and it is said that the author received the first completed copy when on his death-bed. One of the main principles of the theory is that the earth is not at rest but turns round on its axis from west to east once in rather less than twenty-four hours. This real motion of the earth causes the apparent motion of the celestial globe in an

opposite direction, viz., from east to west. An analagous case occurs when a passenger in a moving railway train sees the telegraph posts and other objects apparently flying past him in an opposite direction to his own motion. Copernicus showed how the movements of all the heavenly bodies could be explained by his theory, but was not able to substantially prove that the earth rotated, the only argument then known being that such a supposition was more probable than that the heavens themselves revolved. After the invention of the telescope in 1608, it was found that the sun, moon, and planets all rotated on their shortest diameter or axis, and it was justly argued from analogy that the earth rotated also; but the analogy was not the proof. An objection raised against the Copernican theory was that the earth's motion is not felt. But against this it might be urged that the majestic rotation would not be felt any more than a sailor feels the motion of his ship in a placid sea. We will now, however, give the experimental proofs of the earth's rotation.

(1) Bodies falling from a great height deviate towards the east.—In 1802 experiments were made at Hamburg which consisted of letting bodies fall from the top of a tower 250 feet high and observing the point where they touched the ground. It was found that the bodies had on the average a deviation of about a third of an inch towards the east. In 1831 an abandoned mine shaft in Saxony was used for the same purpose. The fall obtained in this case was 520 feet, and after a hundred experiments it was found that the average deviation towards the east was 1·12 inches. From these experiments, then, we learn that bodies dropped from the top of a high tower fall not at the foot of the tower but slightly to the east of it. The reason of this will be apparent from an inspection of Fig. 56. As the earth rotates in the direction indicated by the arrow, the top of the tower AB must move faster than the bottom, because it has to describe a larger circle. A stone,

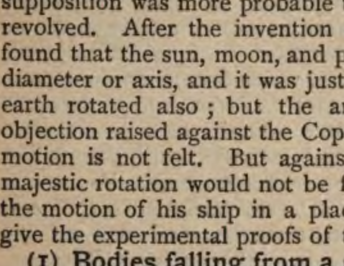


Fig. 56.

Newton's experiment for proving the rotation of the earth. For simplicity the tower may be considered as on the equator. The earth would then appear to revolve in the direction indicated, when observed from above the northern hemisphere.

therefore, at A has a higher velocity than the foot of the tower. Let the stone be dropped from the tower, and let the tower move from AB to A′B′ in consequence of the earth's rotation whilst the stone is falling to the ground. If the stone had remained at A it would have moved over the space AA′ whilst the foot of the tower was moving through the smaller amount BB′, and this excess of velocity which the stone possessed by virtue of a higher position causes it to fall at D, that is, eastward of the foot of the tower instead of falling exactly at the foot. This experiment was first suggested by Newton, but so many sources of error come in that it is not capable of giving very good results. Observers have found that the falling body does not invariably fall to the east of the tower but towards all points of the compass, and it is only by taking the average of a long series of experiments that any fairly reliable result has been arrived at.

(2) Foucault's pendulum experiment.—Foucault devised and carried out an experiment in 1851 by means of which the rotation of the earth can be made visible. (Fig. 57.) A heavy iron ball, about a foot in diameter, was suspended from the dome of the Pantheon in Paris by a wire more than 200 feet long. The ball was held out of a vertical position by a thread, and when quite still the thread was burned and the ball thus let go. It was arranged that a small pin attached to the bottom of the swinging ball should trip and make a mark every time it passed a circular ridge of sand placed on the Pantheon floor. The experiment was made: at the first swing the pin made certain marks in the sand, the second pair of marks were slightly to the left of these, the third pair more so, and had the pendulum kept vibrating long enough, it would at length have cut all the sand away. What is the cause of this

Fig. 57.

Foucault's pendulum experiment for proving the rotation of the earth. The pendulum vibrates in a certain direction, *a a*. The circular table is slowly twisted under it, in the opposite direction to the hands of a watch, because of the earth's rotation.

apparent displacement? Either the direction of the oscillations made by the pendulum is twisted round in the same direction as that of the hands of a watch, or the floor turns under it in the opposite direction to watch-hands. Most people know that it is difficult to push a heavy body out of the path in which it is moving. Consider, then, the heavy pendulum bob described above; it is set vibrating in a certain path, and cannot of itself move out of that path; hence it is inferred from the experiment that the floor and the roof of the building—and, therefore, the surface of the earth—moves from left to right under it. Foucault found by preliminary experiments that the path in which the pendulum vibrated remained fixed when the top of the wire by which it was suspended was twisted, and hence he argued that the motion of the top of the building did not affect the position of the path of vibration, the pendulum keeping in the path in which it was started as if it were not suspended from, or connected with, anything on the earth. Such a pendulum suspended at either of the poles would appear to describe a circle in 23 hours, 56 minutes, 4 seconds, which, we have seen, is a sidereal day, or the true time of rotation of the earth. As we move from the poles to the equator the time taken for the pendulum to describe the circle increases, and at the equator no such motion is observed, the pendulum taking there an infinitely long time to complete the circle of vibrations.

The following table shows the observed and calculated hourly motion of the pendulum plane in a few places having different latitudes:—

Place.	Latitude.	Observed motion per hour.	Calculated motion per hour.
Ceylon ...	... 6° 56′ N. ...	1°·890 ...	1°·815
New York ...	... 40 44 „ ...	9 ·733 ...	9 ·814
Geneva ...	... 46 12 „ ...	10 ·522 ...	10 ·856
Bristol ...	... 51 27 „ ...	11 ·788 ...	11 ·763
Dublin ...	... 53 20 „ ...	11 ·915 ...	12 ·065
Aberdeen ...	... 57 9 „ ...	12 ·700 ...	12 ·636

From experiments with Foucault's pendulum in various parts of the earth, the time of rotation of the earth has been calculated. The result is 23 hours, 53 minutes, 37 seconds, which differs from the true time by only 2 minutes, 27 seconds, and hence is a very close agreement. The exact period of rotation is found by observations of stars with the transit instrument.

(3) **Foucault's Gyroscope.**—Another instrument devised by Foucault for demonstrating the rotation of the earth is called the *Gyroscope*, and consists of a heavy rimmed wheel mounted on gimbals so that it is free to turn in any direction. This wheel is set in rapid rotation in a certain direction, and keeps that direction unchanged in accordance with the law that no body has the power to alter its own state of motion. It corresponds, therefore, to the swinging pendulum just described. A microscope is arranged so as to watch a pointer over a graduated scale, and it is found that the pointer appears slowly to move from right to left, because of the motion of the microscope and scale from left to right.

A sketch of the instrument is shown in Fig. 58.

Fig. 58. A Gyroscope.

A is a heavy rimmed wheel in rapid rotation in the ring B, which is supported inside another ring C, suspended by a thread DE and capable of turning on the point F. As the earth rotates, the microscope and scale are carried round in the opposite direction to watch hands and therefore the end of the pointer S appears to move in the same direction as watch hands.

On account of the earth's rotation bodies moving from the equator to the poles are deviated towards the East.—The above are some experimental proofs of the earth's rotation. We will now consider some phenomena which follow from it. In the first place a point on the equator has to be whirled through a distance of 25,000 miles in about 24 hours, which, roughly speaking, is at the rate of a thousand miles an hour. At the poles, however, there is no rotation. Suppose a cannon at the equator to be fired when pointing due north or south. If the earth did not rotate the ball would travel in a true north and south line; but on account of the rotation of the earth the ball, when it left the cannon's mouth, had a velocity of 1,000 miles an hour from west to east as well as its northern velocity, due to the combustion of the gunpowder. Thus the ball moves from a point where its velocity towards the east is

1,000 miles an hour to parts of the earth where it is much less, and on account of this excess of velocity the ball deviates to the east of the direction in which the cannon was pointed. It will be seen later on that winds and ocean currents suffer the same deviation.

The shape of the earth is that which would result from the rotation of a semi-fluid mass.—We have already shown that the earth is flattened at the poles. It is highly probable that at one time our globe was in a viscous or semi-solid condition, somewhat like thick tar. Now it has been demonstrated by experiment, and proved mathematically, that a plastic body in rotation must assume the spheroidal shape described. All the particles of a rotating mass tend to fly away from the centre of the mass; where the velocity is greatest this tendency is the strongest, hence the equator is bulged out because there the velocity of the particles is greatest, and a slight flattening occurs at the poles where the velocity of rotation is least.

The Sun has an apparent motion among the Stars which it takes a year to accomplish.—Besides the daily or diurnal phenomena, which occur in consequence of the rotation of the earth, other annual phenomena have been observed from the earliest ages. In the first place, the path described by the sun across the heavens is not always the same, and in the summer our luminary describes a larger arc and is higher in the heavens at midday than it is in the winter. (Fig. 59.) The sun has thus an apparent up and down motion in the sky. Again, if we observe the stars which set shortly after the setting of the sun, we shall find that in the course of a few days they will no longer be visible, and other stars, which previously did not set till long after the sun, now accompany him. Similarly, the stars which appear at one time near the sun when it is rising, are after a few days considerably elevated above it at the same time, as if either the stars had moved towards the west or the sun towards the east. These appearances are periodic. The stars which set soon after the sun in the spring will be found to occupy exactly the same relative appearance in the following spring, and those stars which accompany the sun in the autumn will again be found to accompany him in the following autumn. The sun therefore moves eastward among the stars. This regular succession of annual phenomena has, *of course*, been long utilised by man to measure time, and

hence the greater part of the observations of early astronomers had for their object the determination of the positions of the stars relatively to the sun at his rising and setting, by which they fixed the seasons and regulated the operations of agriculture. In consequence of the difference in relative position of the sun and stars in different seasons, it may be noted that different groups of stars, or constellations as astronomers call them, appear

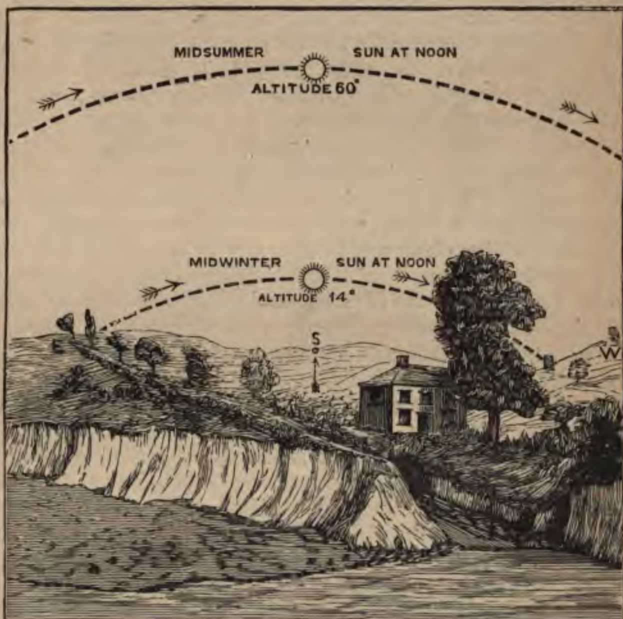


Fig. 59. The difference in the Altitude of the Summer and Winter Sun.

in the midnight sky at different times of the year, are supplanted by other groups, and at the same time in the following year are found in the same position. Thus, in England, an observer might notice a particular star exactly over a particular point on the earth at midnight. A few nights after, the star will be found west of the position at midnight; the distance from the midnight point first observed will go on increasing, night by night, until, as

the season returns in which the first observation was made, the star will approach its original position, and on a particular night will be found again to occupy exactly the same position that it did previously. The interval of time that elapses between these two successive appearances is called a sidereal year—a year measured by the stars.

The Ecliptic is the Apparent Annual Path of the Sun among the Stars.—In consequence of the apparent movement described in the last section, the groups of stars which form the background of the sun are different at different periods of the year. It is not possible to distinguish the light of a match through the brilliancy of an electric arc light. In like manner the feeble light of the stars cannot be seen in the daytime because of the overpowering brilliancy of the sun and the dissipation of its light by the atmosphere. At times, when the sun's rays are cut off, that is, during an eclipse, the bright stars of the background can be generally seen. Bright stars can also be observed in the day by means of a telescope. Early astronomers noticed that the sun always appeared to traverse the same groups of stars, and termed its path the *ecliptic*. They divided the apparent yearly path of the sun among the stars into twelve parts, and the groups of stars extending about eight degrees above it were called *signs of the zodiac*.

The Earth is one of eight planets which revolve round the sun in elliptic paths.—The countless stars with which the celestial vault is sprinkled move together like bright spots upon a solid revolving sky. From their fixed relative positions they have been called *fixed stars*. At certain times objects are seen which do not remain fixed among the stars from night to night. The ancients knew five such objects, and called them *planets*, that is, wandering stars. The moderns have discovered two faint bodies, barely visible to the naked eye, and so brought the list up to seven. All these objects revolve round the sun at different distances from it. The nearest planet, Mercury, has an average distance of 36,000,000 miles from the sun, and the most remote, Neptune, travels round our luminary at an average distance of 2,792,000,000 miles. The earth is a planet which revolves round the sun at a distance of about 93,000,000 miles. The path or orbit in which each planet moves is elliptical in shape, and the sun occupies one of the foci of the ellipse. From this law it is manifest that all *planets are further* from the sun at one end of the major axis of

the orbit than when it is at the other end. When a p[lanet is] nearest the sun it is said to be in *perihelion*, and when farthest away it is in *aphelion*.

The law of gravitation asserts that the force with which bodies attract one another is directly proportional to their masses and inversely proportional to the distance which separates them. This being so, the attraction stress between the sun and a planet is greater when the latter is in perihelion than when it is in aphelion, and, consequently, the nearer a planet is to the sun the faster does it move in its orbit. (Fig. 60.) All the planets revolve

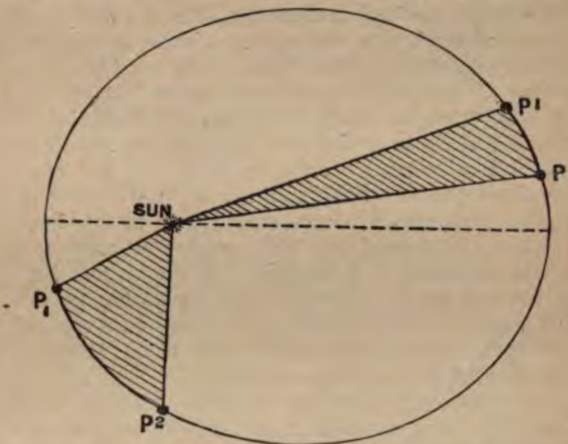


Fig. 60. Illustration of Kepler's 2nd Law. The arc PP^1 is passed over in the same time as P_1P^2, the shaded lines therefore represent equal areas described by the line joining the planet to the sun during equal intervals of time.

round the sun in one invariable direction, which if we could view them from above would be seen to be opposite to that of the hands of a watch. Each planet also rotates on an axis in the same direction. In order to see the motion of the planets in their greatest simplicity, the student should conceive himself stationed at the sun. The stars would be seen fixed in the heavens at an infinite distance away, and the planets would be observed to move among them.

Illustration of the Earth's orbit in comparison with the distances of stars.—Although the distance across the earth's orbit, 186,000,000 miles, may appear enormous, yet it is insignificantly small when compared with the distances of the stars. To get some conception of these dimensions imagine a well-levelled field many miles in extent. On it place a ball, one inch in diameter, to represent the sun. The earth will be proportionally represented by a small shot revolving round the ball at a distance of nine inches. On this scale the nearest star would be about 300 miles away. If we further reduce the scale so that the earth's orbit would be represented by a circle one inch in diameter, the sun would appear as a small grain of sand, the earth as an almost invisible speck of dust, and a tree about eighteen miles away would represent the nearest star. The stars surround our system just as the distant trees surround the orbit imagined above. But they do not only occur on the same level as the earth's orbit, they are above it and below it, and surround it on all sides. If we could take a journey from the earth through space, in whatever direction we travelled, and with whatever velocity, we should never come to an end. Occasionally a star might be met, and then perhaps the monotony of the journey would not be broken for thousands of years. But it is as impossible for our finite minds to conceive this infinite space, as it is impossible for us to have any conception of infinite time, that is, eternity. What should be grasped is that the stars are distributed through space at enormously different distances from the earth, and that, since there is no end in any direction, there is no top or bottom or sides or centre of the universe, hence the words 'up' or 'down' have no meaning when applied to space. All we know is that in one part of space the earth has a motion of revolution round a luminous body called the sun. This has nothing to do with the stars, and the stars have nothing to do with it; indeed, if the light of all the stars were blotted out at any moment things could go on much the same as at present. But it is not sufficient to state that the earth is a planet which revolves round the sun. We must indicate how this motion is proved. In the first chapter we explained how two forces or two motions can have a single resultant, and we now have occasion to use this knowledge.

Aberration Phenomena.—Suppose rain is falling straight down, as we sometimes see it. An umbrella has to be held exactly overhead to shield off the drops, when we stand still;

when, however, we begin to walk, the umbrella has to be tilted forward to catch the drops, and must no longer be held vertically; the faster we walk the more must the umbrella be tilted forward, and the rain no longer appears to fall straight down from the clouds but to fall slantingly and in advance of its true position. Similarly, a traveller in a railway train on a rainy day may observe an increased slant of the direction of the rain-drops falling across the windows when motion commences. Again, if a ship is at rest a shot fired from a distant battery would, if its velocity were sufficient, enter one side of the ship and go out at the opposite side, so that the two shot holes would be exactly opposite each other. But if the ship be moving at right angles to the line joining it to the battery, the hole where the shot leaves the ship will be further astern than that where the shot enters. The distance along the ship from one hole to the other represents the distance advanced by the ship during the time of the passage of the shot across it. Hence, although a person on board the ship would at once be able to judge of the position of the battery when at rest; if he did not allow for the motion of the ship in the second case he would imagine the battery to be in advance of its true position. (Fig. 61.) How much in advance depends upon the velocity of the ship and that of the shot.

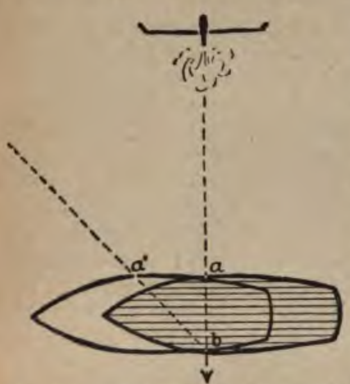


Fig. 61. Illustration of Aberration. A shot entering a ship at *a* would strike *b* if the ship did not move. An observer would therefore be able to tell in which direction the battery lay. But if the ship moved from *a* to *a'* while the shot crossed it, the direction of the battery would appear to be in the line *a'b* instead of *ab*.

Astronomical Aberration.—Experiments have been made which prove that light-waves do not travel instantaneously, but move with a velocity of about 186,000 miles in a second. It can also be proved that light-waves have their apparent direction changed in the same way as falling rain-drops or moving projectiles when the observer is in motion. Now, if the earth were at

rest the position of a star would be the same throughout the year. But stars are not always seen in the same position; they suffer a very small periodic displacement from their average position, that is to say, the direction in which a telescope has to be pointed to look at a star varies slightly. This variation is due to the earth's motion, just as the variation in the apparent direction of falling rain is due to the motion of the observer, and in both cases the displacement is towards the point to which the motion tends.

Constant of Aberration.—The amount a telescope has to be tilted depends upon the velocity of the earth in its orbit, and the velocity of light. If we take the velocity of light as 186,337 miles per second, and the earth's average orbital velocity as 18·5 miles per second, we have the data for determining the angle between the lines joining the observer to the true and the apparent position of a star, a trigonometrical calculation shows that the angle is 20″·5, and this is termed the *constant of aberration*. It is worth while calling attention to the fact that there are 1,296,000 seconds of arc in 360 degrees, so 20″·5 is a very small angle. This is because the earth's velocity is so small compared with the velocity of light.

How the Aberration of Light proves that the earth revolves round the sun.—Consider a star situated in space on the same level as that in which the earth revolves, that is, on the plane of the ecliptic. When the earth is moving towards or away from the star no displacement occurs; the star will be observed in its true place. This is analogous to the fact that the up and down motion of an individual does not cause any change in the apparent direction of vertically falling rain. But when the earth is moving at right angles to the line joining it to the star, a telescope pointing to the star is really directed 20″·5 ahead of its real direction. When, however, the earth is moving along the opposite side of its orbit, the star is displaced 20″·5 in the opposite direction, the displacement being always towards that point of the heavens to which the direction of the earth's motion tends at the moment of observation. (Fig. 62.) We see, therefore, that on account of aberration a star on the ecliptic apparently oscillates 20″·5 on each side of its mean or true position. The time taken for such a star to apparently move 20″·5 on one side, to return to the mean position, to be displaced 20″·5 on the other side, and return again to the mean position—that is, to complete a cycle of changes—is exactly a year. The earth must therefore take a year to travel round the sun. If the sun revolved round the earth and the

earth were fixed in space, the stars would always appear in precisely the same direction. We have only considered a star on the ecliptic for simplicity. All stars suffer displacements which recur every year. But the form of the apparent path described depends upon the position of a star with respect to the ecliptic. As we have seen, stars on the ecliptic oscillate backwards and forwards along a line 41″ long. Generally speaking, however, stars describe ellipses, the major axes of all of which are 41″ long and the minor axes of which increase in length with the distance of stars above the ecliptic, until, at the ecliptic pole, the minor becomes equal to the major axis, and the apparent path described is a circle. The important point to remember is that whether the apparent path described by a star be a straight line, an ellipse, or a circle, exactly a year is taken up in completing the cycle of changes.

Fig. 62. Aberration Ellipse.

When the Earth is at A, B, C, and D the star appears to be at *a*, *b*, *c*, and *d*, that is, in advance of its true position, owing to the motion of the Earth.

Determination of the Sun's Distance by means of the Constant of Aberration.—Knowing the velocity of light (186,337 miles per second) from careful experiments, and the constant of aberration (20″·45) from observations of stars, we can determine the velocity of the earth in its orbit by a simple trigonometrical calculation. The principle of the method is illustrated by Fig. 63. It is thus found that the average velocity of the earth is 18·5 miles per second. The number of miles travelled in a sidereal year (31,558,149 seconds) is therefore 18·5 × 31,558,149. The result obtained is 583,825,756, and this represents the length in

miles of the circumference of the earth's orbit. And since the circumference of a circle contains the diameter 3·1416 times, and the radius is half the diameter, the radius of the earth's orbit, that is, the distance of the earth from the sun, is $\frac{583,825,756}{2 \times 3\cdot1416}$ which is

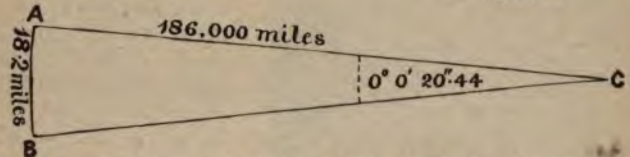


Fig. 63. Calculation of the earth's orbital velocity from the constant of aberration and velocity of light.

equal to 91,330,175 miles. This is, of course, only an approximate value, for the earth's orbit is not circular, consequently the earth does not travel with the uniform velocity assumed in the calculation.

The Annual Parallax of a star is the angle contained between two lines to the star, one drawn from the centre of the earth's orbit, the other from a point on the orbit.—The radius of the earth's orbit is 92,796,950 miles long, and light, travelling at the rate of 186,337 miles per second, therefore takes 498 seconds (about 8 minutes) to pass over this distance. It is impossible to get an idea of the stellar distances by expressing them in miles, so astronomers use another unit called a 'light year,' that is, the distance travelled by light in a year. The nearest star is so far away that light takes about $3\frac{1}{2}$ years to travel from it to us. Most of the stars visible to the naked eye are

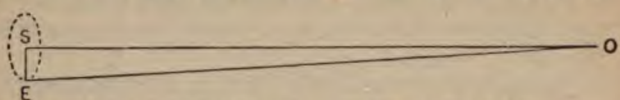


Fig. 64. The Annual Parallax of a star. The angle S O E represents the parallax of the star O.

probably from 200 to 300 light-years distant, and many are thousands of 'light-years' away. It will therefore be seen that the radius of the earth's orbit is very small in comparison with the immense distances of the stars. If an observer on the nearest star could direct a telescope first to the centre of the earth's orbit, and then to a point on the circumference, the

angle between the two directions would only be $0''\cdot75$. This number represents the annual parallax of the star. (Fig. 64.) From the vast majority of stars the sun and the earth would appear as one point of light, that is, there would be no angle between the line joining the star to the centre of the earth's orbit, and that from the star to a point on the circumference; there would be no measurable annual parallax. The more distant a star is, therefore, the less is its annual parallax.

The Annual Parallax of Fixed Stars is a Proof of the Earth's Revolution in an Orbit.—To understand this, let us conceive a circular railway constructed upon a level plain, and ourselves looking down upon it from a balloon (Fig. 65). The earth may be considered to travel in a path

Fig. 65. The change in the apparent direction of an object as the position of the observer is altered.

round the sun similar to an engine moving on the circular railway. When the engine is at A an observer focuses a telescope upon a church tower; or some object at a considerable distance. Let the engine move round to B, the observer will now have to turn his telescope back through a certain angle in order to see the tower, when he arrives at A again he will have to direct his telescope as formerly, so that, because of the motion of the engine in the railway, the position of outside objects undergoes a change, due to the varying positions of the observer. The stars are at such enormous distances from the earth that the diameter of the path in which it revolves round the sun is as a dot in space, and, hence, the light from a star as seen from two positions on the earth's path nearly opposite one another is almost exactly in the same direction. With the increase of delicacy of astronomical instruments, however, it has been found that a star observed at one time appears in a slightly different position about six months later, when the earth is on the other side of its orbit. This difference in apparent position of the star—the annual parallax of the star—may, therefore, be considered as another proof of the earth's orbital revolution.

The Orbit of the Earth is Elliptical in Shape, and the sun occupies one of the foci. This has been determined by accurately measuring the sun's diameter throughout the year.—In consequence of the form of the orbit the earth is about three million miles nearer the sun in winter than in summer. We have now to consider the observations which enable us to decide the exact shape of the path in which the earth revolves round the sun. Daily measurements of the sun's diameter show that it gradually increases from July to January and then decreases from January till July. The diameter of the sun on January 1, 1892, was $32' \, 36\frac{1}{4}''$, whilst its diameter on June 30 was $31' \, 32''$. Only one deduction can be drawn from this, viz., that the earth is nearer the sun in January than in July. It is evident that these variations could not occur if the path in which the earth moves round the sun were circular, for then our luminary would always appear exactly the same size when measured at noon every day throughout the year. By investigating the series of measurements, astronomers have been able to determine that the shape of the earth's orbit is that of an ellipse. It was shown in Chapter V. that every ellipse has two foci, and it has been found by the above method that the sun occupies one of the foci of the elliptical path traversed by the earth in its revolution. In January the distance of the earth from the sun is 90,436,000 miles, in July, 93,564,000 miles.

QUESTIONS ON CHAPTER VI.

1. State one experimental proof of the earth's rotation. (1891.)
2. Describe the apparent annual motion of the stars due to the earth's revolution round the sun. (1888.)
3. State some observations which prove that the earth is not flat, and some which prove it to be more or less globular.
4. Give a brief description of the methods used to determine the exact size and shape of the earth.
5. What observations indicate that the sun has an apparent motion among the stars? What is the ecliptic?
6. How has it been found that the earth revolves round the sun, and not the sun round the earth?
7. How has the shape of the earth's orbit been determined? (1892.)
8. What are the facts which prove that the earth revolves round the sun and not the sun round the earth? (1892.)

CHAPTER VII.

THE PLANE OF THE ECLIPTIC AND PLANE OF THE EQUATOR, WITH SOME EFFECTS WHICH RESULT FROM THEIR NON-COINCIDENCE.

The Plane of the Ecliptic is the plane described by the line joining the centre of the Sun to the centre of the Earth.—Consider the path of the earth represented by an elliptical but very nearly circular railway on a level plain, and let an electric light be fixed in the ellipse to represent the sun. The engine will travel round the electric light always on the same level or plane. Transfer your thoughts from the imaginary engine and the electric light to the earth and sun in space. The earth travels round the sun in one plane, on one level, as definitely fixed as was the plane in which the engine moved round the electric light. It does not bob up and down, but floats round the central body like a ship in a perfectly placid sea. This plane in which the earth performs its revolution is called the *plane of the ecliptic*, and a line joining the centres of the earth and sun must always lie in it.

The Plane of the Equator is not identical with the Plane of the Ecliptic.—If the earth floated upright in the ecliptic plane, the equator would coincide with it, and the axis would be at right angles to it. Summer would then occur when the earth was nearest the sun, and all over the earth our luminary would cross one particular path in the sky, and would attain at mid-day a certain altitude which, although different for different latitudes, would always be the same for the same latitude. But the sun does not appear to describe the same arc in the sky throughout the year, hence the earth does not float upright in the ecliptic plane. The majority of people have observed that the shadows of all objects decrease in length from sunrise to noon and then increase to sunset, and it is fairly evident that shadows are shortest when the sun is highest in the sky. If a post be fixed in the ground, the length of its shadow, measured at noon throughout the year, will be found to decrease from spring to summer, to reach a

shortest length and appear to have the same length for several days, to increase in the autumn to the length measured in the spring, and in the winter to be much longer than in summer. As an example of the great difference in the length of the shadow it may be mentioned that the Eiffel Tower, which is 984 feet high, has a shadow about 3,060 feet long in December, and 478 feet long in June, the difference being 2,582 feet.

The Sun's Declination varies from $23\frac{1}{2}°$ North to $23\frac{1}{2}°$ South in a Year.—The angular distance of the sun from the zenith, and therefore its altitude or angular distance from the horizon, may be determined by measurements of the lengths of the shadow of

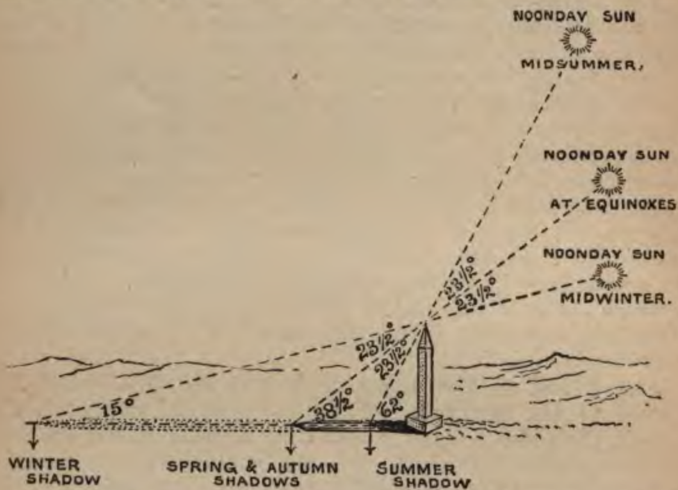


Fig. 66. The Gnomon. Method by means of which the Obliquity of the Ecliptic ($23\frac{1}{2}°$) has been determined. The altitudes given are for the latitude of London.

a fixed object at different times in the year. A column erected perpendicular to the horizon for the purpose of determining the altitude of the sun is called a *gnomon*, and it is known that many of the Egyptian obelisks were erected primarily to serve as gnomons. Indeed, such observations as the above described have been made from time immemorial, and careful measurements show that from spring to summer the sun describes arcs of increasing size, and on midsummer day at noon is $23\frac{1}{2}°$ higher than it was at

noon in mid-spring. It then appears to describe the same arc for a few days, and little change is perceptible in its mid-day altitude. This point is called the *Summer Solstice*. From midsummer day, however, the sun gradually describes lower arcs, and in autumn has returned to the point it occupied in spring. At these times the days and nights are everywhere of equal length, and the earth is said to be at the *Spring and Autumnal Equinox* respectively. From autumn to winter the sun's altitude at noon decreases, and in midwinter is $23\frac{1}{2}°$ below the spring and autumn points. Again the sun appears to have nearly the same altitude for a few days, and the earth is said to be at the *Winter Solstice*. After midwinter day the sun begins to describe arcs which daily increase in size. The transit instrument allows much more accurate observations to be made of these changes, than is possible with a gnomon.

The Obliquity of the Ecliptic is the angle between the plane of the ecliptic and the plane of the equator.—What deductions can be made from the above observations? We know that the earth revolves in one plane, and that the sun's apparent path is in the same plane. The observations with a gnomon, or transit instrument, show that the sun moves from $23\frac{1}{2}°$ South declination to $23\frac{1}{2}°$ North declination and back again in a year. The variation in declination proves that the plane of the equator is not coincident with the ecliptic plane, and the measurements show that the inclination of one to the other—the angle contained between the two planes—is $23\frac{1}{2}°$. This is termed the *obliquity of the ecliptic*. (Fig. 67.) The earth's axis is perpendicular to the plane of the equator, and points to the celestial poles. In like manner the poles of the ecliptic are the two points in the heavens directly above a perpendicular to the plane of the ecliptic. They are therefore 90° distant from the ecliptic. The angle between the earth's axis, and a perpendicular to the plane of the ecliptic, is the same as the

Fig. 67.

The Obliquity of the Ecliptic, or the inclination of the Equatorial to the Ecliptic plane.

K

obliquity of the ecliptic, viz., $23\frac{1}{2}°$. The earth's axis is therefore inclined $90° - 23\frac{1}{2}°$, that is, $66\frac{1}{2}°$ to the plane in which it revolves round the sun. This inclination remains the same throughout the whole period of the earth's revolution. If, therefore, we could view the earth and the sun from some point in space nearly on the same level as the ecliptic plane, the northern and southern hemisphere would be seen alternately tilted towards the sun and away from it, whilst at two other parts of the orbit the earth's axis would neither be inclined to, nor away from, our luminary. These variations may be well illustrated by sticking a knitting needle through an orange or ball of worsted to represent the earth's axis, and then carrying the orange or ball horizontally round a lighted lamp, with the knitting needle always pointing in the same direction. The lamp takes the place of the sun, and objects on the wall, ceiling, and floor of the room represent the stars which surround our little system on all sides.

The variations in the sun's declination throughout the year are due to the inclination of the earth's axis to the ecliptic plane.—The orbit of the earth may be represented by an oval wire loop. If the loop be viewed from a point slightly above, the form of the earth's orbit will appear very elliptical, and if the

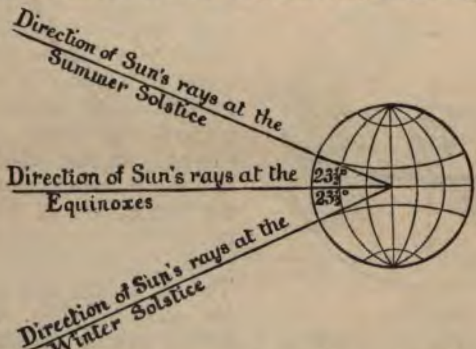


Fig. 68. Variation in the direction of the sun's rays throughout the year.

loop be viewed edgeways, only a line of wire is seen. Consider yourself in space, and on a level with the plane of the equator. At the summer solstice the sun is $23\frac{1}{2}°$ above the equatorial plane, that is, its declination is $23\frac{1}{2}°$ North. But at the winter solstice the sun is the same number of degrees below the

equatorial plane; its declination is $23\frac{1}{2}^\circ$ South. At the equinoxes the sun is on the equatorial plane, in other words, the plane of rotation coincides with the plane of revolution. At such times, therefore, the sun's declination is 0°. (Fig. 68.) In illustration of the same point let us consider the alterations of the sun's zenith distance at London throughout a year.

At the summer solstice the sun's declination is $23\frac{1}{2}^\circ$ North, that is, it is vertical over the tropic of Cancer (lat. $23\frac{1}{2}^\circ$). Taking the latitude of London as $51\frac{1}{2}^\circ$ N., the difference ($51\frac{1}{2}^\circ - 23\frac{1}{2}^\circ$) is found to be 28°. And this difference represents the distance of the noonday sun from the zenith of London at the summer solstice. The altitude at this time is therefore 62°. When the sun is on the equator—at the equinoxes—its zenith distance at London is $51\frac{1}{2}^\circ$, and hence its altitude is $38\frac{1}{2}^\circ$. At the winter solstice the sun is vertical over the tropic of Capricorn (lat. $23\frac{1}{2}^\circ$ S.). Its zenith distance at London is thus $51\frac{1}{2}^\circ + 23\frac{1}{2}^\circ = 75^\circ$, and so its noonday altitude is 15°.

The annual change of the sun's declination causes the sun's amplitude of rising and setting to vary throughout the year.—When the arcs described by the sun are increasing in size, that is from winter to summer, our luminary is apparently moving towards the north; as they decrease in size it moves southward. These changes can be determined by observing the points on the horizon at which the sun rises and sets during different times of the year. Thus at the summer solstice the sun's declination is $23\frac{1}{2}^\circ$ North, and the direction of rising in London is about forty degrees north of the east point, and of setting, forty degrees north of west; at the winter solstice the sun rises about forty degrees south of the east point, and sets forty degrees south of west; and it is only at the equinoxes, when the declination is 0°, that it rises and sets due east and west. The distance of the rising and setting sun at the solstices from the east and west points increases with the latitude of the place of observation. The following are the amplitudes for a few latitudes:—

Latitude.	Amplitude of the Sun at the Solstices.
10°	$23\frac{1}{2}^\circ$
20	$24\frac{1}{2}$
30	$27\frac{1}{2}$
40	$31\frac{1}{2}$
50	$38\frac{1}{2}$
60	52

At the equinoxes, that is, when the sun's declination is 0°, it rises due east, and sets due west all over the world.

The two points where the ecliptic cuts the Equator mark the two Equinoxes.—If a celestial globe be examined a great circle will be found drawn upon it, cutting the equator at two points. From one of the points of intersection the circle may be traced upwards to a declination of $23\frac{1}{2}°$; it then curves downwards to the other point, passes to $23\frac{1}{2}°$ below the equator, that is, to a declination of $23\frac{1}{2}°$, after which it curves upwards to the first point of intersection. This great circle is the ecliptic, and it represents the apparent annual path described by the sun among the stars. The point where the sun crosses the equator from south to north is the *vernal* or *spring equinox;* the point at which the sun crosses the equator from north to south represents the *autumnal equinox.* Astronomers term these two points *nodes*, the former being known as the ascending node, and the latter as the descending node. The imaginary line joining the equinoctial points, or nodes, is termed the *line of equinoxes* or *line of nodes.*

The position of the Sun at the Spring Equinox is the 'First Point of Aries.'—In the time of Hipparchus (B.C. 150) the line joining the two equinoctial points pointed in one direction to the constellation Aries, in the other to Libra. When this was the case, the sun was in Aries at the spring equinox, and in Libra at the autumnal equinox. The point in the sky occupied by the sun at the spring equinox, that is, one of the points where the plane of the ecliptic intersects the plane of the equator, is taken as the starting point for reckoning the longitudes of stars in the same way that the meridian at Greenwich is taken as the starting point for measuring terrestrial longitude. It is known as the 'First Point of Aries.' Owing to the fact that the earth is not a perfect sphere, but has what can be considered as an extra belt of matter round the equator, the line joining the equinoctial points or nodes does not constantly point in the same direction, and now, instead of pointing to Aries, it points to Pisces. Hence, the sun is now in Pisces at the spring equinox, and in Virgo at the autumnal equinox. This movement of the equinoctial points round the ecliptic to meet the Sun is called the *precession of the equinoxes.* It amounts to about 50″ per annum, so that a revolution is completed in about 26,000 years. But, notwithstanding the fact that the equinoctial line no longer points to Aries, that, in fact, the *'signs'* of the Zodiac no longer correspond with the zodiacal

constellations, astronomers still call the position of the sun at the spring equinox the First point of Aries and count the longitudes of stars from it.

Effects of the Precession of the Equinoxes.—The equinoctial points or nodes mark the intersection of the plane of the earth's equator with the plane of the ecliptic. They move round the ecliptic plane once in about 26,000 years, hence the north and south poles of the earth, and the celestial poles, which are above them, also move round the north and south poles of the ecliptic in the same time; and hence if we imagine an observer living on the north pole of the earth, he would see our present pole star slowly get further and further away from the zenith in centuries of observation, and other stars would take its place. And since the declination of stars is dependent upon the position of the celestial poles they would be gradually changed. Another effect of precession is to alter the seasons which occur when the sun occupies a certain position in the heavens. We have seen that the cause of the seasons is the inclination of the plane of the earth's equator to the ecliptic plane, and it will be understood from the accompanying figure that in 13,000 years summer will occur at that point of the orbit which the earth now occupies at winter. Similarly, all the seasons are, so to speak, slowly moving round the earth's orbit. In 13,000 years the sun will be projected upon the constellation Virgo at the spring equinox; spring will occur when the earth is in that portion of its orbit which it now occupies at autumn; and summer and winter will have changed places.

The two points on the ecliptic most distant from the equinoctial points mark the solstices.—The line of solstices is at right angles to the equinoctial line, each of the solsticial points of the earth's orbit being midway between the equinoxes. At the time when the sun was in Aries at the spring equinox it was in Cancer at the summer solstice and Capricorn at the winter solstice. But the position of the line of solstices depends upon that of the line of equinoxes, hence, owing to precession, the sun is now projected upon Gemini at the summer solstice, and is near Sagittarius at the winter solstice.

The succession of the seasons depends upon the revolution of the earth and the inclination of its axis.—It would appear at first sight that winter should occur in all parts of the world when the earth is most distant from the sun (aphelion), and summer when nearest the sun (perihelion). But

as a matter of fact the winter solstice occurs near the perihelion point of the earth's orbit, and the summer solstice near the aphelion point. (Fig. 69.) On account of the constant inclination

Fig. 69. The Earth's Orbit in space.

of the earth's axis to the ecliptic plane, the northern and southern hemispheres are alternately turned towards our luminary and turned away from it during a revolution round the sun (Fig. 70). It is to this inclination of the earth's axis that we have to refer the cause of the seasons. When we have summer in the northern hemisphere, the sun rises high in the sky and radiates its light and heat directly down upon us. The people in the southern hemisphere then have winter, because they are turned away from the sun. When however, six months later, winter occurs in the northern

hemisphere, then summer occurs in the southern hemisphere. At the equinoxes the sun is directly over the earth's equator and

Fig. 70. Illustration of the cause of Summer and Winter.

appears midway between the highest and lowest points reached by it in a year. This is because when the earth is at either of these points the axis is neither turned towards the sun nor turned away from it, but the globe is lit up as shown in Fig. 71.

Fig. 71. Appearance of the Earth at the Equinoxes.

The dates at which the earth passed the equinoxes and solstices in 1892 are as follows:—

Spring or Vernal Equinox	...March 20.	Spring begins.
Summer Solstice	...June 20.	Summer begins.
Autumnal Equinox ...	...Sept. 23.	Autumn begins.
Winter Solstice	...Dec. 21.	Winter begins.

Why it is hotter in Summer than in Winter.—It requires a little consideration to understand why the high suns of summer and the low suns of winter should have such effect upon the temperature of our globe. The atmosphere surrounding our globe stops much of the sun's light and heat, and therefore the greater the thickness of atmosphere traversed the less is the amount received. When the sun's rays are passing almost vertically through the atmosphere the greatest amount of light and heat are received. As the rays become less and less

vertical, however, more and more light and heat are absorbed by the atmosphere, and less received at the earth's surface. In addition to this we have the fact, that when it is summer in the northern or the southern hemisphere the sun describes a larger arc and the days are consequently longer; hence, more heat is received in the day than is lost at night. In the winter the reverse is the case. The earth thus gets hotter and hotter during summer, cooler and cooler in the winter. This accumulation of heat causes the highest summer temperature in our latitude to occur not when the sun rises highest in the sky on midsummer day, but about July 26. For a like reason, the lowest temperature does not occur on midwinter day, but the end of January, and the mean temperatures of the year do not occur at the equinoxes, but on April 24 and October 21 respectively. We may, therefore, say it is hotter in summer than in winter because (1) the sun is more nearly vertical, and (2) the days are longer than the nights.

The Tropics are circles in the Northern and Southern hemispheres of the Earth over which the Sun is vertical at the solstices.—Since the sun in a year travels $23\frac{1}{2}°$ north and $23\frac{1}{2}°$ south of the equator, it must be in the zenith at noon twice each year at every portion of our globe which lies between these limits of latitude. Thus, at a place in latitude 10° the sun is vertical at mid-day when it is travelling northwards and its declination is 10°, and also when it is travelling southwards and its declination is 10°. This belt, 47° in width, is called the *torrid zone*, and the lines bounding it are called *Tropics* because the sun appears to 'turn back.' In it the days and nights are nearly uniform throughout the year. North latitude $23\frac{1}{2}°$ is called the *Tropic of Cancer*, and the south parallel $23\frac{1}{2}°$ the *Tropic of Capricorn*.

The Arctic and Antarctic circles border the regions within $23\frac{1}{2}°$ of the North and South Poles.—We have previously shown that when the sun or a star is in the zenith of an observer at the equator, it is theoretically just on the horizon of an observer at either of the poles, that is to say, the sun is visible at places within about 90° of the place where it is in the zenith. This being so, when our luminary is on the tropic of Capricorn in $23\frac{1}{2}°$ south latitude, he is just on the horizon of an observer in a latitude 90° distant, that is, in $66\frac{1}{2}°$ north latitude; while all places still further north do not see him at all. Similar reasoning applies to the case when the sun is on the tropic of Cancer. The parallels of latitude 90° away from the tropic of

Capricorn and the tropic of Cancer are respectively called the Arctic and Antarctic Circles, and the two regions round the poles bounded by them, and therefore embracing $23\frac{1}{2}°$ of north and south latitude, are known as the *North and South Frigid Zones*.

Day and Night at the Poles.—The sun is on the equator at the equinoxes, and therefore would appear on the horizon of an observer at either pole. The horizon of such an observer is a plane passing through the centre of the earth and perpendicular to the direction of a plumb-line. But this plane is identical with the plane of the equator, hence at the equinoxes the sun appears to remain on the horizon of an observer at the poles for a whole period of rotation—twenty-four hours. From March 20 such an observer at the north pole would see the sun describe a sort of spiral path in the sky until, on June 21 (the summer solstice), a circle having an altitude of $23\frac{1}{2}°$ would be reached. After this the path is retraced downwards until the date of the autumnal equinox, when the sun would appear once more on the horizon. Throughout this period, that is, from the vernal to the autumnal equinox, the sun is visible at the north pole. It then passes below the equator in its southern course and sinks below the horizon to return again at the vernal equinox. In like manner, from the autumnal to the vernal equinox, the sun is visible at the south pole, but invisible at the north pole. Day and night at either pole are therefore each about six months long.

At places within the frigid zones there is at least one day in a year when the Sun does not set for twenty-four hours. — At the summer solstice the sun is vertical over the tropic of Cancer (latitude $23\frac{1}{2}°$), and its beams light up the whole of the north frigid zone. In consequence of this, places within the zone continue in sunlight for a whole period of the earth's rotation. As the sun's north declination decreases, the region which receives the sun's rays for twenty-four hours also decreases. Thus, when the sun's declination is 10° it does not set at those places situated within 10° of the pole; when its declination is 5° it does not set at places within 5° of the pole, and so on, until when the declination is 0° the pole is the only point lit up for twenty-four hours. Hence, at the arctic circle (latitude $66\frac{1}{2}°$) the sun is seen at midnight only on the day of the summer solstice. As the sun moves further towards the south the region around the north pole which receives no sunlight increases in area until at the winter solstice the whole of the north frigid zone remains in darkness

for a day, whilst the whole of the south frigid zone is in light. We see, therefore, that so long as the northern declination of the sun is equal to or greater than the distance of an observer from the north pole, the sun will be visible. And when the southern declination is equal to or greater than this distance the sun will be invisible. It results from this, that within the frigid zones at least one day occurs in a year at which the sun is seen during an entire rotation of the earth, and at least one day occurs when the sun is not seen for twenty-four hours. Places situated above latitude $66\frac{1}{2}°$ are therefore said to be in the 'Land of the Midnight Sun,' and about the date of the summer solstice trips are frequently run to Norway to enable people to see the sun at midnight.

The belt extending from either tropic to the corresponding polar circle is called the Temperate Zone.— In this zone there is always true day and night, that is, alternations of light and darkness in twenty-four hours, but the lengths of each vary throughout the year, and are dependent upon the latitude of the place of observation. We know that the days increase in length as the sun's northern declination increases, as the arcs described in the sky get larger, and that the longest day occurs at the summer solstice. They then shorten as the sun moves southwards, and the shortest day occurs at the winter solstice. The following table shows that the length of the longest day increases with the latitude, whilst the length of the shortest day decreases.

Latitude.	Longest Day.	Shortest Day.
0°	12 hours 0 mins.	12 hours 0 mins.
10	12 " 35 "	11 " 25 "
20	13 " 13 "	10 " 47 "
30	13 " 56 "	10 " 4 "
40	14 " 51 "	9 " 9 "
50	16 " 19 "	7 " 51 "
60	18 " 30 "	5 " 30 "
$66\frac{1}{2}$ (Arctic Circle)	24 " 0 "	0 " 0 "
70	2 months	
80	$4\frac{1}{2}$ "	
90 (Pole)	6 "	

The Stars contained in one half of the heavens are permanently visible at the poles, and never rise or set.— *Consider an observer* at either of the poles. The celestial pole

(which is above the earth's axis of rotation) coincides with his zenith, and he is theoretically able to see all the stars situated between it and the celestial equator which forms his horizon, but none below the equator. Such an observer at the north pole could never see stars in the southern hemisphere, neither could an observer at the south pole see stars north of the equator. In consequence of the earth's rotation the stars would appear to describe circles around the celestial pole, the size of which depends upon their declination. (Fig. 72.) Stars situated near the equator would appear to travel from east to west at a slight distance above the horizon, stars further north of the equator would describe circles parallel to these, but of greater altitude, and so on, the size of the circles gradually decreasing upwards to the zenith. In order to observe a particular star, therefore, it would only be necessary to adjust a telescope to the proper altitude, and it could be followed until sunlight blotted it out. Thus, stars would not appear to rise above the horizon, and afterwards to set below it, as is the case in latitudes other than 90°.

Fig. 72.
Paths of Stars to an observer at the North or South Pole.

In middle latitudes Stars occur (1) which never set, (2) which never rise, (3) which rise and set.—We have shown that the altitude of the celestial pole is equal to the latitude of a place. In London, therefore, the pole is $51\frac{1}{2}°$ above the horizon. Stars whose angular distance from the pole is less than this never set to observers in London or any place having the same latitude, and are said to be circumpolar. To understand this, consider a star 10° distant from the pole. It appears to describe a circle around the pole at a constant distance of 10°. A star whose polar distance is 20° appears to travel around a circle at the constant distance of 20°. In like manner, a star whose polar distance is $51\frac{1}{2}°$ goes round the pole at the

distance of $51\frac{1}{2}°$. At one point of its journey it is $51\frac{1}{2}°$ above the pole, and at another it is $51\frac{1}{2}°$ below the pole, that is, on the horizon, but it can never go below the horizon. The same reasoning applies to any other latitude, all stars being circumpolar whose distance from the pole is less than the observer's latitude. Thus, the size of the circle containing circumpolar stars decreases in passing from the poles to the equator. If the elevation of the north celestial pole is $51\frac{1}{2}°$ the south pole is depressed below the horizon by the same amount. And it will be seen from the accompanying illustration (Fig. 73) that stars situated within $51\frac{1}{2}°$ of the south pole will never rise above the horizon of this latitude. In other words, stars whose distance from the depressed pole is less than the observer's latitude can never be seen in that particular latitude. Besides the stars which never set, and those which never rise, others may be seen to rise in the east, to travel across the heavens in oblique circles, and to set in the west, as shown in the accompanying figure. It will be seen that stars above the equator travel along a greater part of their path above the horizon than below it. Thus, to an observer in London, a star whose north polar distance is, say, 60°, only has a very small portion of its path cut off by the horizon. Stars on the celestial equator travel along half of their path above the horizon and half below it, that is, they are above the horizon for the same time as they are below it. Stars below the equator are above the horizon for a shorter time than below it.

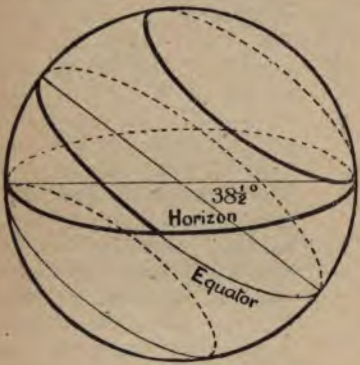


Fig. 73.
Paths of Stars to an observer in the latitude of London ($51\frac{1}{2}°$).

At the Equator all the Stars in the heavens rise and set vertically during one complete rotation of the earth. —An observer at the equator has the north and south celestial poles on his horizon. A star on the equator would rise straight *up from the east point,* pass through the zenith, and then sink

straight down to the west point. All other stars would rise and set vertically and describe circles parallel to the equator. (Fig. 74.) The size of the circles, however, depends upon the star's declination. A star having a declination of 45° would always be seen to rise 45° north of east, that is, N.E., to traverse a small circle, and to set 45° north of west, that is, N.W. Similarly, stars with south declination rise always at definite points south of east and set south of west. But whatever be the size of the path described by a star, half of the journey is performed above the horizon and half below it, that is to say, at the equator all stars appear above the horizon for twelve hours, and are below it for the same time. If the sun did not exist all the stars in the heavens could be seen in a single day by observers at the equator. During the day (which is always twelve hours long) the sun extinguishes the feeble light of the stars by the brilliancy of its beams, so that only the stars in the hemisphere opposite to that occupied by the sun are really seen.

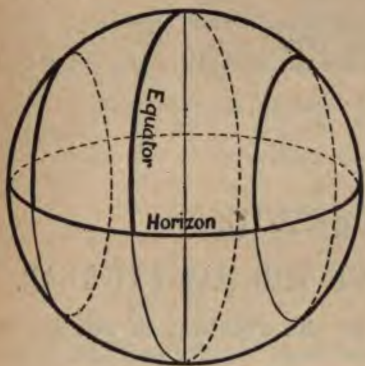


Fig. 74.
Paths of Stars to an observer at the Equator.

The cause of the differences in the apparent paths of stars considered in the last three sections is that although the plane of a star's motion is practically constant during a rotation, the plane of an observer's horizon may cut it at points which differ according to the latitude of the place of observation. At the poles the plane of the horizon coincides with the plane of the earth's rotation, and therefore stars describe horizontal paths. In middle latitudes the plane of the horizon cuts the plane of rotation obliquely, the result being that the stars appear to travel across the sky in oblique paths. At the equator the horizon plane is perpendicular to the plane of rotation, and therefore the stars move in vertical paths.

QUESTIONS ON CHAPTER VII.

1. What difference is observed in the plan of the rising and setting of the sun (1) at different times of the year at any place in the British Isles, (2) at the summer solstice in different parts of the northern hemisphere? (1891.)

2. How has it been shown that the plane of the earth's equator is inclined to the plane of the ecliptic? What is the amount of that inclination? (1890.)

3. What differences occur in the apparent paths of the stars across the sky as we proceed from the equator to the poles? What is the cause of this difference? (1889.)

4. Explain by diagrams why the sun appears high in the sky at noon in summer, and low at noon in winter. (1889.)

5. State what you know concerning the variation in the length of the day and night in different parts of the world at different times of the year. (1887.)

6. Why, in this country, does the sun appear so much higher in the sky at noon in summer than it does in winter? (1886.)

7. Why are the days and nights of different lengths in summer and winter? (1885.)

8. State some of the effects of the precession of the equinoxes.

CHAPTER VIII.

THE MEASUREMENT OF THE DAY AND YEAR.

Day and Night occur as the rotation of our globe causes one half to be turned towards the sun and to be in light, while the other is turned away from the sun and in darkness.—It is easy to understand how objects may appear to move when they are really fixed. An observer in a railway train in motion sees every thing outside apparently flying past him in an opposite direction to that in which he is moving, and he knows that the appearance is produced by his motion. Similarly, our earth's rotation on its axis causes the appearance of movement of the heavenly bodies in an opposite direction.

As a consequence of this rotation we get day and night. Let Fig. 75 represent the earth and the sun as seen if we were looking down upon it in space. The sun can only light up one half of the globe at one time, the other half being turned away from it will be in darkness. Hence, only one half of our earth can be lit up at one time and enjoying day, the other half will be in the darkness of night. Consider an observer in England at midday, with the sun overhead. As the earth rotates other places are

brought directly under the rays of our luminary, hence in about twelve hours the observer will arrive at a point opposite the sun

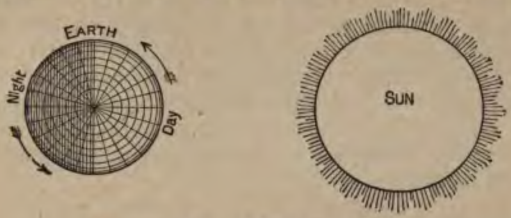


Fig. 75. Cause of Day and Night.

and it will be midnight; and in about another twelve hours he will again have midday.

Meridians, or Lines of Longitude, are semicircles supposed to be drawn on the earth's surface from the North to the South Pole through any place.—They are generally reckoned up to 180° W. and 180° E. of Greenwich, but any meridian may be taken as the starting point. Conceive the equator divided up into 360 parts and let a line be drawn

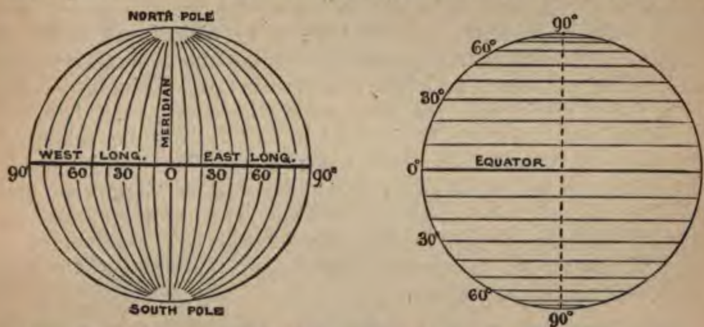


Fig. 76. Meridians and Parallels. Longitudes are reckoned from the prime meridian. Latitude from the equator.

from the north to the south pole through each of them. There will thus be 360 lines marked on the earth similar to those shown in Fig. 76. The direction of each line is exactly north and south, and any two of them exactly opposite each other form a great

circle which divides the earth's surface into two halves or hemispheres. These lines are called meridians of longitude. At the equator the length of a degree is $\frac{1}{360}$th of the circumference of the earth, or 69·1 miles. If this be divided up into sixty parts or minutes, the length of a minute is found to be 1·15 miles, and this length—that is, the sixtieth part of a degree on the equator—is called a knot or geographical mile. Hence, 60 geographical miles = 1 equatorial degree = 69·1 statute miles.

The following table shows the length of a degree of longitude in different latitudes :—

Latitude.	Miles in 1° of Longitude.	Latitude.	Miles in 1° of Longitude.
0°	69	50°	44½
10	68	60	34½
20	65	70	23½
30	60	80	12
40	53	90	0

It is manifest from the foregoing that the sun will reach its highest point at the same time at all places on the same north and south line or meridian. When the sun reaches this point, which is approximately half-way between the eastern and western points of the horizon, it is said to be on the meridian: we then have noon or midday, and the time is 12 o'clock. The hours before noon are denoted by a.m. (ante meridiem), which signifies before the meridian, and hours after noon are distinguished by p.m. (post meridiem), meaning, after the meridian. Let the meridian passing through Greenwich Observatory be taken as the starting point, then there are 180 meridians of longitude conceived to be drawn upon the globe west of Greenwich, and 180° conceived to be drawn east of Greenwich, or 360 altogether. Hence 180° west longitude must coincide with 180° east longitude, and places on this meridian must be in midnight when it is Greenwich noon or midday.

Relation between Longitude and Time.—In consequence of the earth's rotation the sun appears to pass over each of the 360 meridians of longitude in 24 hours, that is, at the rate of 15° in an hour or 1° in four minutes. The sun crosses the meridian at places east of Greenwich before it crosses the Greenwich meridian, hence when it is noon at Greenwich it is afternoon at such places. Further, when it is 12 o'clock at Greenwich it is four minutes to twelve at places 1° west of

Greenwich, and 11 o'clock at places 15° west. Let a watch be regulated so as to keep exact Greenwich time, that is, let it always indicate 12 o'clock when the sun crosses the Greenwich meridian. Take the watch to any part of the globe and note what is the time by it when the sun reaches its highest point. If the time indicated by the watch when the sun was on the meridian be two hours after noon, then we should know that the sun crossed the Greenwich meridian two hours previously, and since two hours of time are equivalent to 30° of longitude, we should be in a place 30° west or behind Greenwich. Hence, at any place west of Greenwich the watch would indicate time *after* noon and at any place east of Greenwich time *before* noon, when the sun crossed the meridian. For the purpose of determining longitude by this means, ships always carry one or more well regulated watches or chronometers keeping Greenwich time. It is, of course, immaterial which meridian is used as the standard of reference. The Greenwich meridian is the one adopted in Britain, Paris is the one adopted in France, and the Island of Ferro by Germany. Efforts have been and are being made to establish a universal meridian, but not with much success.

The following are some longitudes of towns expressed in angles and in the time equivalent to them :—

	Longitude. In Angle.				Longitude. In Time.			
Greenwich - - -	0°	0′	0″		0 h.	0 m.	0 s.	
Cambridge - - -	0	5	41	E.	0	0	22·8	E.
Dublin - - - -	6	20	30	W.	0	25	22	W.
St. Petersburg - -	30	18	22	E.	2	1	13·5	E.
Washington - -	77	3	1	W.	5	8	12·1	W.
Calcutta - - -	88	27	56	E.	5	53	52	E.
Pekin - - - -	116	24	45	E.	7	45	39	E.
Melbourne - - -	144	58	42	E.	9	39	54·8	E.
Antipodes Isle - -	179	30	0	E.	11	58	0	E.

When a place has east longitude the above times represent the amount by which local time is ahead of Greenwich time; and when a place has west longitude, local time is a certain amount behind Greenwich time. Perhaps the most striking example of difference of longitude is brought out by means of the electric telegraph. The time taken for telegraphic messages to travel any distance on the earth may be taken as nothing. If, therefore, a signal be sent from Greenwich at noon any day to Calcutta, although it travels instantaneously, yet it is nearly six

o'clock in the evening local time when it arrives there, and a telegram sent to Dublin at Greenwich noon reaches there about 11.30 a.m., local time.

A Sidereal Day is the interval between two successive transits of the same Star over the same meridian.—To return to our illustration of the earth's orbit, represented by a small circle in a large field, with distant trees in every direction. Let the earth be represented by a minute ball in rotation. It will be seen that no matter in what position the ball may be on the circumference of the circle, so long as the time of rotation is the same a particular tree would always appear in the same direction after the same interval of time. In like manner the interval that elapses between two successive appearances of a star in the same position is always the same, and is called a *sidereal day*. It is divided up into twenty-four equal parts called hours (sidereal) and minutes and seconds as in ordinary time. The starting point of the sidereal day occurs when the 'First point of Aries' transits at any place. The position of this point is accurately known to astronomers. When it crosses the meridian, therefore, a clock which keeps sidereal time should indicate 0 hours, 0 mins., 0 secs. It is then sidereal noon. In every observatory there is a clock which keeps sidereal time. If a star is observed to transit when the time by the sidereal clock was, say, 14 hours 35 mins. 16 secs., it is said that the star's *right ascension* is 14 hours, 35 mins., 16 sec.; right ascension may therefore be defined as the sidereal time at the moment when a celestial object crosses the meridian. It corresponds to terrestrial longitude, and the First point of Aries is the equivalent of Greenwich.

The True or Apparent Solar Day is the time that elapses between two successive appearances of the Sun on the meridian of a place, and is indicated by a Sun-dial.—If we observe the interval of time from noon to noon, as indicated by the sun's shortest shadow, on different days in the year, we find that it is not at all constant according to our clocks and watches. Thus, in September, the solar day would appear to be about 50 seconds shorter than in December. A clock or watch to keep time with the sun must have its rate altered from day to day. It would appear therefore that for a uniform standard of measurement of time the sidereal day is the most simple, since it is always of the same duration, but the southing of the sun at noon is so much more important and *manifest a phenomenon* than the transit of stars, that it has always

been used to mark the day in spite of the variability of time from noon to noon at different times in the year.

Why a Day measured by a Star is four minutes shorter than a Day measured by the Sun.—It has been stated that whereas the interval of time between two successive passages of a star across the same meridian is 23 hours 56 mins. 4 secs., the day as measured by the sun is four minutes longer. To understand this, suppose a star could be seen in the day-time exactly in the same direction as the sun. On the following day the star appears in the same position four minutes before the sun, on the next day eight minutes before, and so on, until in a year the sun is about a day behind the star. We have shown that this apparent easterly movement of the sun among the stars is due to the revolution of the earth. If we consider the earth's orbit as circular, the earth sweeps over a little less than $1°$ a day, therefore the sun appears to move away from a star at the same rate. The reason for the difference between sun-time and star-time will also be seen from an inspection of Fig. 77. Let A represent the earth in a certain position in her orbit, and let the sun and an infinitely distant star be just crossing a meridian together; when the same star comes on the meridian again the earth will be in the position B, but the sun will not come on the meridian until the earth has rotated through the arc *a b*, and hence the solar day is longer than the sidereal day by the time the earth requires to rotate through this arc. The lines *a c* and *b c* are practically parallel to each other because the stars are so far away, so that the earth always rotates through exactly $360°$ in the time that elapses between two successive meridional passages of the same star, and therefore a sidereal day must always be of the same length, since the time taken by the earth to make one rotation is always the same. In order to form a solar day, however, the earth has to rotate through the angular distance, measured at the sun, which it has passed over in its orbit, in

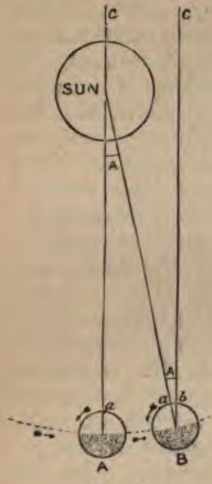


Fig. 77.
Cause of the difference between a Solar and a Sidereal day.

addition to the 360° through which it rotates to bring the star on the meridian. This angle is about 1°, and the earth takes four minutes to rotate through this amount.

The Mean Solar Day is twenty-four hours long, and is the average of the lengths of all the true solar days throughout the year.—For the purpose of convenience the lengths of all the days in a year are added up, and the average length found and rightly termed the mean solar day. This is used for all purposes of civil life, as it marks the recurrence of light and darkness, and does not ever differ more than 16 minutes 20 seconds from the actual length of the day. The *civil day*, or 'day' as generally understood, is of the same length as the mean solar day. It is reckoned from midnight to noon, and then from noon to midnight. The *astronomical day* is reckoned from mean noon to mean noon through 24 hours, and has no a.m. or p.m. It begins at 12 a.m. civil time, hence the civil day is always 12 hours in advance of the astronomical day. All clocks and watches should keep mean solar time, and the meaning of the expression *Greenwich mean time* (abbreviated G.M.T.) will now be understood to be the time as regulated by the average interval between two successive passages of the sun across the Greenwich meridian.

The Difference in the Lengths of the Solar Days throughout the year is due to (1) The eccentricity of the earth's orbit, (2) The obliquity of the ecliptic. On account of the first cause the earth moves with varying speed in its orbit. In passing from aphelion to perihelion its velocity gradually increases, and conversely, in passing from the point nearest the sun to that most distant, the velocity decreases. But the apparent motion of the sun among the stars is entirely dependent upon the real motion of the earth, hence the apparent easterly movement of the sun in the ecliptic is continually varying throughout the year. It is greatest in January, when the earth is nearest the sun, and least in June, when the earth is most distant. The result is that the day as measured by the sun-dial is longer than the 'mean' day in the former month and shorter in the latter. In consequence of the second cause the apparent eastward motion of the sun is greatest at the solstices and least at the equinoxes, and is subject to a constant variation between these times.

Mean time is time kept by an imaginary sun moving uniformly along the equator at the same average rate as *the real sun in* the ecliptic.—In January the real sun moves

through an angle of $1^\circ\ 1'\ 10''$ in twenty-four hours, whilst in June the angle described in the same time is only $0^\circ\ 57'\ 12''$. In a year it travels 360°, and if it moved at a uniform rate the angle described in a day would be $\frac{360^\circ}{365}$, that is, $59'\ 9''$. This is the average or mean daily rate of the sun in the ecliptic. Astronomers imagine a sun to move uniformly at this rate along the celestial equator, and call it a 'mean sun.' This fictitious body therefore travels completely round the equator in exactly the same time that the real sun moves round the ecliptic. The motion of the real sun in the ecliptic gives us apparent solar time, and *apparent noon* at any place occurs when this body crosses the meridian. This is therefore the time indicated by a sun-dial. *Mean noon* occurs when the imaginary mean sun crosses the meridian, and as the mean sun is supposed to travel with uniform velocity along the equator, the interval of time from mean noon to mean noon is always the same, and equal in length to a mean solar day. The time indicated by clocks and watches (mean time) is therefore regulated by the mean sun.

How and why the eccentricity of the Earth's orbit and the obliquity of the ecliptic cause the inequalities of the periods which elapse between successive passages of the Sun over the same meridian. —Let us first only consider the effect of the eccentricity of the earth's orbit, in consequence of which the sun moves with variable velocity in the ecliptic. From the time of perihelion to that of aphelion the sun's apparent velocity is decreasing, whilst from aphelion to perihelion it is increasing. Suppose a 'mean' sun with mean angular velocity to start with the real sun at the time of perihelion (in January), and move along the ecliptic. At the instant of starting the two bodies will cross over a certain meridian at the same time, and apparent noon coincides with mean noon. The motion of the true sun from successive apparent noons will be indicated by a sun-dial, whilst the motion of the mean sun is measured by a clock keeping mean time. We suppose, therefore, that sun-dial time and clock time coincide at the starting point. In 24 hours the real sun will have described an angle of $1^\circ\ 1'\ 10''$, whilst the mean sun has travelled over $59'\ 9''$. Hence, as far as the eccentricity of the earth's orbit is concerned, the real sun will cross the meridian after the mean sun. (Fig. 78.) Sun-dial time at this season will therefore lose when compared with clock-time. The interval between apparent

and real noon goes on increasing so long as the angular velocity of the real sun exceeds that of the mean sun, that is, up to March, when the velocities of the two bodies are equal. The sun-dial will then have lost about eight minutes when compared with the clock. From March to June the daily angle described by the real sun is less than that travelled by the mean sun. The angle by which the former body has shot ahead of the latter during the first three months is therefore daily decreased, and therefore the eight minutes taken by a meridian to pass from the mean to the real sun is daily diminished. Thus the sun-dial appears to gain from day to day when compared with the clock. It goes on

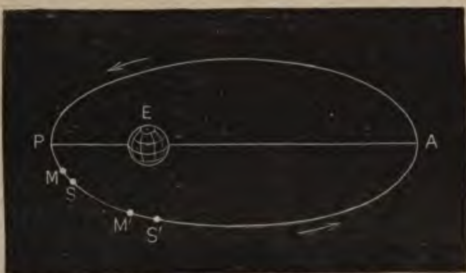


Fig. 78. M M′ positions of the 'mean' sun. S S′ positions of the 'true' sun. E, the earth. A meridian on the earth is brought to M and M′ sooner than to S and S′.

gaining until at the time of aphelion (in June) it has made up the time that it had previously lost, and the true and the mean sun again cross the meridian together. Similar reasoning will show that the reverse action occurs from the time of aphelion to that of perihelion. From June to September the true sun drops behind the mean sun. It therefore comes on the meridian before the mean sun, that is, sun-dial time gains. In September eight minutes has been gained, but from this month to December the same amount is lost, so that in the latter month the clock and the sun-dial again agree, the true sun and the mean sun again cross the meridian at the same time.

We will now consider the effect of the inclination of the plane of the equator to the plane of the ecliptic—the obliquity of the *ecliptic*.

Suppose the true sun moved in the ecliptic with uniform angular velocity, and the mean sun moved along the celestial equator at the same rate, and that the two bodies were started from the first point of Aries at the same instant. Each of them has, then, the same right ascension, viz., 0 h. 0 m. 0 s. The mean sun moving over equal angles along the equator increases its right ascension by the same amount daily. But the right ascension of the sun moving in the ecliptic does not increase at the same rate on account of the obliquity of the ecliptic. Fig. 79. From the spring equinox to the summer solstice the true sun will

Fig. 79. How the obliquity of the ecliptic causes a difference between real and apparent time.

cross a given meridian before the imaginary one moving along the equator. At the solstice both will have described 90°, and will cross together; the imaginary sun then falls behind the true sun until the autumnal equinox, when the two again coincide. In like manner, from the autumnal equinox to the winter solstice, the imaginary sun gets ahead in right ascension, and then falls behind to the spring equinox. Thus, as far as the obliquity of the ecliptic is concerned, the two suns coincide four times a year (the two equinoxes and the two solstices), and therefore cross a given meridian together at these seasons. The greatest difference between the times of transit of the real and imaginary suns, due to this cause, is nearly ten minutes, and occurs about February 15, May 7, August 8, and November 3.

The Equation of Time is the amount to be added to or subtracted from true solar time to convert it to mean solar time.—The two causes of the inequalities in the lengths of the days which have just been referred to do not, of course, act separately, as they have been considered, but together. Their combined effect causes sun-dial time at some seasons to coincide with clock time, and at other periods to be ahead of or behind it. The difference between the two times is called the 'equation of time.' The effects of the two causes are best seen by combining them graphically as in Fig. 80. Points are taken along the horizontal line to represent the months in a year, whilst the vertical line on the left side is divided into

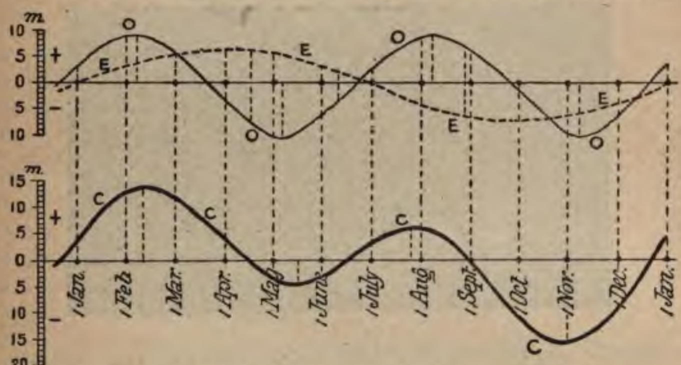


Fig. 80. Graphical representation of the Equation of Time.

equal parts to represent minutes. Starting at perihelion (January 1st) the effect due to the eccentricity of the earth's orbit is indicated by the curve E E E E, which shows that if it alone acted seven minutes would have to be added to apparent time to bring it to mean time about April 2nd; coincidence would occur on July 1st; apparent time would require to have seven minutes subtracted from it to bring it to mean time on October 1st, and on January 1st the two would again coincide. The effect of the obliquity of the ecliptic is shown in a similar manner by the curve O O O O. It will be seen that at several periods of the year the two causes act in opposite directions. Thus, in May the eccentricity of the earth's orbit tends to make apparent time behind mean time, whereas the obliquity of the ecliptic tends to

make it ahead. In February, each of the two causes tends to make apparent time behind mean time. By combining the two effects in this manner all through the year the curve C C C C is obtained, which represents graphically the equation of time. The parts of the curve above the horizontal line show the amounts which have to be added to apparent time to bring it to mean time at different periods in the year, whilst the portions below indicate the amounts which have to be subtracted. The value of the equation of time is given for every day in the year in the 'Nautical Almanack' and other publications. The following are the dates of coincidence and the maximum amounts by which the apparent or sun-dial time differs from mean or clock time.

February	11	...	Apparent time	14 mins. 32 secs. slow.
April	15	...	"	Correct.
May	14	...	"	3 mins. 54 secs. fast.
June	14	...	"	Correct.
July	26	...	"	6 mins. 12 secs. slow.
Sept.	1	...	"	Correct.
Nov.	2	...	"	16 mins. 18 secs. fast.
Dec.	24	...	"	Correct.

The sidereal year is the interval of time that elapses between two successive conjunctions of the sun with the same fixed star. It is 365 days 6 hrs. 9 mins. 9 secs. long.—When the sun is in conjunction with a star, the two bodies are on the same celestial meridian. Suppose a star could be seen in conjunction with the sun. A day after, the latter body would be a little to the east of the former. The distance would go on increasing day by day, and in 365 days 6 hrs. 9 mins. 9 secs. the sun and the star would again be in conjunction. A sidereal year is therefore the time that the sun occupies to travel around the ecliptic. To an observer on the sun it represents the exact time taken by the earth to make a complete revolution along its orbit.

The tropical or equinoctial year is the interval of time that elapses between two successive passages of the sun through the same equinoctial point. Its length is 365 days 5 hrs. 48 mins. 46 secs.—If the equinoctial line had a fixed direction in space the tropical year would be of the same length as the sidereal year. But on account of precession the vernal equinox advances towards the west 50·2″ in a year; hence

the sun, which is moving eastward, meets the equinox sooner than it would otherwise do, and hence the tropical year is shorter than the sidereal year by the time the sun requires to move through the angle $50''\cdot2$, that is, about twenty minutes.

The anomalistic year is the time that elapses between two successive passages of the sun through the perihelion or aphelion point. Its length is 365 days 6 hrs. 13 mins. 48 secs.—The line joining the solsticial points of the earth's orbit (the line of apsides) makes a complete revolution towards the east in 108,000 years. The result is that the earth has to go a little more than around its orbit ($11''\cdot77$ more) in passing from perihelion to perihelion, or aphelion to aphelion. The sun, therefore, has to describe $11''\cdot77$ more than 360° in the ecliptic on account of the eastward movement of these points of reference. The time required to pass over this angle is nearly five minutes; hence the anomalistic year is nearly five minutes longer than the sidereal year.

The civil year is of the same length as the tropical year. It begins on January 1st, and consists of twelve months each containing a whole number of days.—As the times of the seasons are regulated by the position of the sun with respect to the equinoxes, the average length of the year used in ordinary life for the measurement of time should be the same as that of the tropical year. But the tropical year does not consist of an exact number of days, hence, in order that the average civil year, containing a whole number of days, should be equal in length to the tropical year, some civil years must be longer than the tropical year and some shorter. In B.C. 46 Julius Cæsar, with the aid of an astronomer named Sosigenes, instituted a year of 365 days, and ordained that one day should be added every fourth year (leap-year), so that the average year should be $365\frac{1}{4}$ days long. The year began in January, and the spring equinox fell on March 25. Since the length of the tropical year is 365 days 5 hrs. 48 mins. 46 secs., and the Julian year has a length of 365 days 6 hrs. 0 mins. 0 secs., the former is 11 mins. 14 secs. shorter than the latter. This difference is about a day in 130 years. Consequently the vernal equinox appeared to occur a day earlier every 130 years, until in the 16th century (1582) it fell on March 11 instead of March 21, as it did at the Council of Nice (A.D. 325). To bring back the church festivals to the position they occupied in A.D. 325, Pope Gregory XIII. directed that the following reforms of the calendar should be made.

(1) October 5, 1582, was called October 15, thus adding ten days, and bringing the spring equinox to March 21. (2) Leap-years to be as heretofore, except that the century years (1600, 1700, &c.), should only be leap-years when they are divisible by 400. Thus 1600 and 2400 are leap years, but not 1800 or 1900. This change gives three days less in 400 years than the Julian calendar, and makes the average length of the civil year 365·2425 days, whilst that of the tropical year is 365·242216 days. In order to make these two numbers exactly equal, a further correction of one day has to be omitted from the calendar about every 4,000 years. The Gregorian calendar was adopted by all Catholic countries immediately after its formation, but was not adopted in England until 1752, and is not commonly used in Russia even at the present time.

QUESTIONS ON CHAPTER VIII.

1. What is the 'Equation of Time' and what use is made of it? (1890.)
2. What is sidereal and what is mean time? (1889, 1892.)
3. What is the relation between Longitude and time? Describe a method of determining longitude.
4. What is the difference in length between a sidereal day and an apparent solar day? Explain the cause of the difference.
5. State the causes of the difference in lengths of solar days throughout the year.
6. Define 'sidereal year,' 'tropical year,' 'anomalistic year,' 'civil year,' and give the length of each.

CHAPTER IX.

COMPOSITION AND CHARACTERISTICS OF COMMON ROCK-FORMING MINERALS.

The crust of the Earth is that part of the whole mass which can be got at and studied.—The structure and constitution of the earth's crust is determined by observations of:—

(1) The materials which make up the surrounding land surface;

(2) Quarries, railway cuttings, sea-cliffs, wells, and mines;

(3) The materials brought to the surface by means of boring rods;

(4) The substances in solution in springs;

(5) The products ejected during a volcanic eruption.

Such examinations as these enable us to know something of the character of the crust down to about 15 miles below the earth's surface. And since the highest mountain (Mount Everest) is only about five and a half miles above sea-level, we may say that our knowledge of the earth's crust is limited to a thickness of about 20 miles. Taking, therefore, the radius of the earth as 4,000 miles, only $\frac{20}{4000} = \frac{1}{200}$ of its length is capable of being directly investigated.

The chemical elements of which the Earth's crust is chiefly composed.—One half the weight of the rocks which constitute the earth's crust consists of oxygen. Silicon is the next in order of abundance, and makes up one quarter the weight of the crust. The seven elements, which, together with oxygen and silicon, form 99 per cent. of the crust, are aluminium, iron, calcium, sodium, potassium, magnesium, and hydrogen. The following is a table of the estimated proportional weights of these elements in the terrestrial matter with which we are acquainted. It does not of course represent the constitution of

the crust as definitely as if all parts of it had been chemically analysed:—

Oxygen	48·0
Silicon	29·0
Aluminium	8·0
Iron	6·0
Calcium	3·0
Sodium	2·0
Potassium	2·0
Magnesium	1·5
Hydrogen	0·2
Carbon ... ... / Sulphur ... ... / Chlorine ... ... / Nitrogen, &c.	0·3
Total	100·0

For the properties of these elements, see pp. 73—75.

A mineral is a homogeneous inorganic natural substance, having a more or less definite chemical composition.—In general language, all substances that can be dug up or mined (*e. g.*, coal) are called minerals. Strictly speaking, however, coal is not a mineral, inasmuch as it has not a definite chemical composition. Slate, sandstone, and flint are common examples of minerals. Although minerals generally occur in a solid form, some (*e.g.*, mercury and petroleum) are liquid at ordinary temperatures. Simple minerals are those consisting of a single chemical element. Most minerals, however, are composed of two or more elements.

The minerals most commonly found in rocks are tabulated below in the order of their per centage proportion. Their composition and character are described further on in this chapter:—

Felspars	48 per cent.
Quartz	35 "
Micas	8 "
Talc	5 "
Carbonates of Lime and Magnesia ..	1 "
Amphibole (hornblende) ... ... / Pyroxene (augite) ... ... / Diallage ... ... / Peridot (olivine)	1 "
Clays	1 "
Various other substances	1 "

The proportions are shown graphically in Fig. 81. Felspars and quartz are much more abundant than the other common rock-forming minerals. Although the latter is less abundant than the former, when considered as a separate mineral, it is really a more abundant chemical compound, because its constituents enter into the composition of felspars and many other minerals.

Fig. 81. Graphic representation of the proportion of rock-forming minerals.

The most important binary compounds occurring in mineral bodies.—The following table shows the proportion in which the most abundant binary compounds exist in the minerals which make up the earth's crust. It will be seen that silica is by far the most common of these compounds.—

Name of Compound.	Names of Elements.	No. of parts by weight.
Silica	Silicon and Oxygen	61·7
Alumina	Aluminium and Oxygen	15·0
Oxides of Iron	Iron and Oxygen	8·3
Lime	Calcium and Oxygen	4·2
Soda	Sodium and Oxygen	2·7
Water	Hydrogen and Oxygen	2·7
Magnesia	Magnesium and Oxygen	2·5
Potash	Potassium and Oxygen	2·4
Other binary compounds		0·5
		100·0

The proportions are shown graphically in Fig. 82. The different rocks in which these compounds occur are described later on (pp. 171—178). We note here, however, that silica occurs abundantly in every rock except limestone. Alumina occurs in clays, shales, slates, &c., and in all rocks having felspar or mica as constituents. Iron occurs in most rocks as one or other of its oxides. Lime occurs in marbles, limestones, gypsum, dolomite, &c. Soda, in combination with other binary

compounds, forms the native nitrates and carbonates of soda. Sodium occurs in large quantities as rock salt (sodium chloride). Potash occurs in granite and similar rocks.

Fig. 82. Graphic representation of the proportion of binary compounds in the earth's crust.

Methods of Examining Minerals.—In examining a new mineral the first thing to do is to make a chemical analysis of it, and from this determination of the proportion of the elements it contains, to deduce its general formula. Many qualities possessed by minerals appeal directly to the senses, and in some cases serve to identify different specimens. Such characteristics are, smell, taste, touch, colour, transparency and lustre (which may be metallic, pearly, silky, etc.). The *fracture*, that is, the appearance exhibited by a broken surface, is also of use in determining the texture of a mineral. Some substances are only capable of being divided in one or more fixed directions—a quality known as *cleavage*. The *streak* of a mineral, that is, the colour of the line produced when the mineral is drawn across a sheet of white paper or a slab of unglazed porcelain, is often a very characteristic test.

The Hardness of Minerals varies considerably. In order to be able to express this character in a definite manner the following scale of hardness has been constructed:—

1. Talc.	6. Felspar.
2. Rock-salt.	7. Rock-Crystal (Quartz).
3. Calcite.	8. Topaz.
4. Fluor-spar.	9. Corundum.
5. Apatite.	10. Diamond.

Each of these substances can be made to scratch any of those preceding it, whilst it can only be scratched by any following it. To determine the hardness of a mineral we find out which substance of the above scale it is just capable of scratching, working downwards from the hardest member (diamond). In this manner it would be found that although a sharp edge of a piece of mica will not scratch calcite it will make a scratch on rock-

salt. Its hardness is therefore between 2 and 3, and may be taken as 2·5. It is useful to remember that minerals having a hardness less than 2·5 can be scratched by the thumb-nail, and those less than 6 may be marked with a good knife.

The Specific Gravity of minerals is often utilised to identify species. It should therefore be determined with precision. One method is to weigh the mineral in air and in water by means of a delicate chemical balance. The specific gravity is then found by dividing the weight in air by the loss of weight in water (see p. 30). Another method is to obtain a non-corrosive liquid having a high specific gravity (say 3·3). The mineral under examination is placed in this and water is added until it just floats. The specific gravity of the mineral is then the same as that of the diluted solution, which latter may be found by the ordinary specific-gravity-bottle method. The specific gravity of powders, such as sand, and substances easily broken up is best found by means of the specific-gravity-bottle.

Effect of raising the temperature.—Magnetic oxide of iron is black at ordinary temperatures, but becomes reddish-brown on being heated, and litharge changes from a brownish colour to yellow under similar circumstances. Some minerals fuse more easily than others. Many substances (*e.g.* red oxide of mercury) on being heated give off gases. In certain cases some of the gases re-condense in the cooler part of the tube, forming a sublimate. With mercuric oxide a grey sublimate of mercury is formed and serves to distinguish the body under examination. The yellow sublimate formed when iron pyrites is heated is composed of sulphur, and cinnabar gives a black sublimate of mercuric sulphide. Many minerals, when moistened with hydrochloric acid and held in the flame of a spirit lamp or bunsen burner, tinge the flame with a characteristic colour. Thus common salt gives a brilliant yellow colouration, and copper a brilliant green. Other tests consist in heating a bit of the mineral on charcoal in the flame of a blowpipe, or in touching it with a fused bead of borax and noticing the resulting colouration. Finally, it may be observed that effervescence occurs on adding an acid to any carbonate, and gelatinous or powdery silica may be separated when a strong acid is added to siliceous minerals.

A Crystal is a many-sided natural solid of definite geometrical form, produced when most substances are allowed slowly to solidify or separate out of solution.—*The formation* of crystals has already been considered (p. 82), and

is the most important characteristic of mineral bodies. In most crystals the 'faces' or 'sides' are plane surfaces, but in a rare few, such as the diamond, they are slightly curved. The axis of a crystal is an imaginary line around which the parts of a crystal are symmetrically arranged. It is impossible to enter at any length into the numerous crystalline forms in this book. We can merely say that crystals are divided into systems according to the relations between their faces and axes, and give a general idea of the characteristic forms of each system, mentioning at the same time minerals which exemplify them :—

(1) The Cubical System.	Examples.
Three equal axes, each perpendicular to the other two.	Fluor-spar. Garnets. Galena.


Fig. 83.

(2) Tetragonal System.	Examples.
Three axes, all at right angles, but only two equal.	Zircon. Tinstone. Apophyllite.


Fig. 84.

(3) Rhombic System.

Three axes, all at right angles, and all unequal.

Examples.

Aragonite.
Topaz.
Sulphur (from solution).

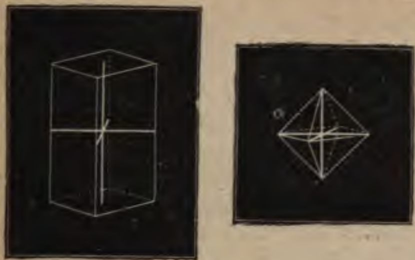


Fig. 85.

(4) Monoclinic System.

Two axes inclined to each other, and one at right angles to both. All unequal.

Examples.

Orthoclase.
Borax.
Sulphur (after fusion).

Fig. 86.

(5) Triclinic System.

Three unequal axes, neither at right angles to either of the others.

Examples.

Axinite.
Copper sulphate.
Bismuth nitrate.

Fig. 87.

(6) Hexagonal System.	Examples.
Four axes, three equal in the same plane at 60° to each other, and one at right angles to these.	Calcite. Quartz. Emerald.

Fig. 88.

It is not to be supposed that the same minerals always occur in the same crystalline forms, for as a matter of fact this is not so. Thus calcite crystallises in probably more than a thousand different forms. This property is known as *heteromorphism*. The point to be insisted upon, however, is that whatever the number of forms, they are all mathematically related to each other, and that however much crystals of the same substance may vary in form and in the relative size of similar faces, the angle between such faces remains constant. As shown above, sulphur crystallises in two forms, and is said to be *dimorphous*. Calcite and aragonite are dimorphous modifications of carbonate of lime, and by heating the latter it may easily be made to split up into small crystals of the former.

All the solid constituents of the crust of the earth are called rocks.—The popular meaning of the word *rock* is a mass of stony material, but in geology, such substances as sand, gravel, clay and mud are known as rocks, as well as hard masses of materials like granite, sandstone and coal.

Granites are made up of three distinct minerals called quartz, felspar and mica.—Granite is generally of a red, white or grey colour. If a piece of this rock be examined it will be seen to be composed of three distinct substances. One of these, called felspar, has a pale red or white colour, and crystals of it may be distinctly seen lying in numerous patches. Mica, another of the constituents, has a brownish or black colour, and occurs in glistening crystalline plates easily scratched with

a knife. Filling up the interstices between the other crystals a third substance named quartz will be found in clear, glossy granules, on which a knife makes no impression. These three minerals enter most abundantly into the composition of rocks, and they will now be described more fully.

Silica (SiO_2) is the most abundant binary compound occurring in mineral bodies.—This, the only known oxide of silica, occurs in nature crystalline, as quartz and tridymite, and non-crystalline or amorphous, as opal. Many other minerals are mixtures of these varieties with each other and with various impurities.

Quartz is the most important form of silica. It occurs in rocks filling up the spaces between the crystals of other minerals. Its own crystals are generally made up of a six-sided prism with a six-sided pyramid on each end. (Fig. 89.) Three sides of each pyramid are invariably larger than the other three, and crystals are often found distorted. But in all cases the angle between two adjacent sides is the same, viz., 120°. The sides of the prism are always marked by transverse striations, whilst those of the pyramids have a smooth polished appearance. *Rock-crystal* is a pure and transparent variety of quartz, and is the *Brazilian pebble* often exhibited by opticians, and used for making spectacle glasses. There are numerous coloured varieties of which we need only mention *amethyst*, which possibly owes its purple colour to a trace of oxide of manganese.

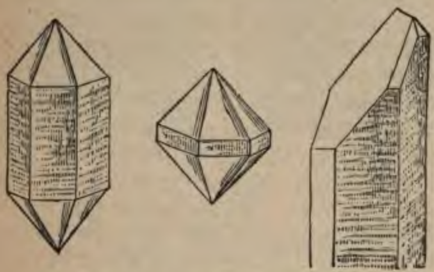


Fig. 89. Crystals of Quartz.

Tridymite is a second crystalline variety of silica. Its specific gravity is 2·3, whereas that of quartz is 2·6.

Opal is the amorphous, hydrated form of silica. Its specific gravity is the same as that of tridymite, and it differs from quartz in being much more soluble in alkalies. *Chalcedony* is a mixture of quartz and opal. *Agates* are chiefly made up of *alternating layers* of chalcedony and quartz, the silica of which

they are constituted existing in the crystalline, amorphous, and mixed forms. *Flint* is a brown or black variety of compact silica which occurs only in chalk.

Felspars are silicates of aluminium in combination with one or more silicates of potash, soda, or lime; after quartz they are the most important rock-forming minerals.—The following are the compositions of a few typical felspars:—

Orthoclase or Potash-felspar (K_2O_1) (Al_2O_3) $(6SiO_2)$.
Albite or Soda-felspar (Na_2O) (Al_2O_3) $(6SiO_2)$.
Anorthite or Lime-felspar $(CaO)_2$ $(Al_2O_3)_2$ $(SiO_2)_2$.

But this composition may vary within very wide limits, for there is every gradation between the typical felspars given above. The purest variety of potash-felspar—*sanidine*—is as colourless as rock-crystal. Felspars show marked cleavage in two directions which in orthoclase are exactly at right angles to each other. On the other hand, albite and anorthite have their cleavage directions separated by slightly less than a right angle. This difference serves to divide the felspars into two groups, respectively represented by orthoclase and albite. Potash is the chief base of the former group, which crystallises in the monoclinic system, whilst the latter group crystallises in the triclinic system and has lime and soda for the chief bases. Some other characteristics of felspars are as follow: (1.) Specific gravity, 2·5 to 2·8. (2.) Hardness, 6. They are therefore softer than quartz, but cannot be scratched with a knife. (3.) Very difficult to fuse. (4.) Colour always light, and usually white, red, yellow, or pink.

Micas are remarkable for their very perfect cleavage in one direction.—This eminent cleavage enables mica to be split up into thin elastic sheets. The specific gravity of minerals of the mica group varies from 2·5 to 3·0. Their hardness is about 2·5, that is to say, mica can be scratched by a knife or a bronze coin and generally by the thumb nail. Micas have a very complex chemical composition, hence the formulæ are not given in the following list of three varieties:—

Muscovites ... Silicates of Potash and Aluminium.
Biotites ... ... „ of Magnesium, Iron, and Aluminium.
Chlorites, Hydrated „ of Magnesium, Iron, and Aluminium.

Muscovite varies in colour from white to light brown, and is the only mica which occurs in large sheets. It is commonly used

instead of glass for lanterns or stoves, and in Russia is often employed for windows. Biotite is black, or nearly so, and chlorite is green.

Silicates are formed by the combination of Silica with metallic oxides.—In that which precedes it will have been seen that a large number of minerals consist of silicates. The following are a few more of this group of minerals :—

Name of Mineral.	Chemical Composition.
Amphibole (Hornblende) ...	Silicate of Calcium, Magnesium, and Iron.
Pyroxene (Augite)	Silicate of Calcium, Magnesium, and Iron.
Diallage	Silicate of Calcium, Magnesium, and Iron.
Olivine (Peridot)	Silicate of Magnesium and Iron.
Serpentine	Hydrated Silicate of Magnesium.
Talc	Hydrated Silicate of Magnesium.
Clay	Hydrated Silicate of Aluminium.

Both the amphiboles and pyroxenes may contain alumina, soda, and other oxides in addition to those indicated above. Common black hornblende is fairly abundant, and contains a large proportion of iron, whilst in *tremolite*, which is found in white or greyish crystals, scarcely a trace of iron occurs. *Asbestos* is a fibrous and incombustible variety of hornblende used in certain kinds of gas-stoves. Although the chemical compositions of amphiboles and pyroxenes are similar, the former group has a higher specific gravity than the latter, and crystallises in a different system. The two forms are capable of passing insensibly from one to the other. Thus, if a piece of hornblende be melted and allowed to cool slowly, crystals of augite are formed. Diallage is an altered form of augite. Olivine is one of the chief constituents of meteorites. When seen in rocks it generally appears in small gum-like grains. In the crystalline form it will take a high polish and may be worked into gems, of which peridot is an example. Olivine easily decomposes, hence, in rocks, it seldom presents its crystalline outline or proper clear colour. The chief alteration is the taking up of water, and the result is the formation of Serpentine—a beautiful mineral much prized for its use in making indoor ornaments. Mica is known commercially as Talc. The latter is easily distinguished from the former, by its *want of elasticity.* It is one of the softest minerals. The

amorphous form of talc is steatite, soapstone, or potstone. The purest kind of clay is Kaolin, or China-clay, used for the manufacture of porcelain. It proceeds from the decomposition of the felspars of granite.

And here it may be remarked that flint-glass is a mixture of silicates of potassium and lead, and crown or window glass is a mixture of silicates of calcium, sodium, and aluminium. Coloured glasses are made by adding certain metallic oxides to glass while it is melted. By heating such silicates as occur in glass, with water in strong steel vessels, it is possible to separate out silica in the form of quartz, having precisely the same characteristics as the natural crystals. Garnets, rubies and other gems have thus been artificially produced, and recently, by similar means, hornblende.

Carbonates are formed by the combination of carbon dioxide with metallic oxides.—The following are a few important carbonates:—

Name of Mineral.	Chemical Name.	Chemical Formula.
Calcite.	Carbonate of Calcium	$CaCO_3$
Magnesite.	,, Magnesium	$MgCO_3$
Dolomite.	,, Calcium & Magnesium	$CaMg(CO_3)_2$
Chalybite.	,, Iron...	$FeCO_3$

Calcite, or Iceland spar, is the purest form in which carbonate of lime occurs in nature. If a piece of calcite be placed upon a page of a book, or upon a piece of paper upon which a dot has been made, two images of the object will be observed, one of which revolves round the other when the crystal is turned. (Fig. 90.) This property earns for calcite the name of *double-refracting* spar. *Aragonite* has the same chemical composition as calcite, but it has crystallised differently. It is neither so abundant nor so stable a compound as calcite. Marble and limestone are other forms of calcium carbonate. Dolomite, or magnesian limestone, is formed by the crystallising together of calcite and magnesite, the proportions of

Fig. 90.
Double refraction by Iceland spar.

these two minerals being very variable. Chalybite is a very abundant and important iron ore which is also found mixed with calcite.

Sulphates can be considered to be formed by the combination of sulphur dioxide with metallic oxides.

ANHYDROUS SULPHATES.

Anhydrite	=	Sulphate of Calcium	=	$CaSO_4$
Barytes	=	„ Barium	=	$BaSO_4$

HYDRATED SULPHATES.

Gypsum	=	Sulphate of Calcium	=	$CaSO_4 + 2H_2O$
Epsomite	=	„ Magnesium	=	$MgSO_4 + 7H_2O$

Anhydrite is a form of calcium sulphate found in nature free from water. Gypsum, the hydrated variety of the compound, is a much more abundant mineral. In the crystalline form it is known as *selenite*, and when massive, as *alabaster*, the latter being extensively used instead of marble for the manufacture of statuettes and other small ornaments. By carefully heating gypsum the greater portion of the water of crystallisation is given up, and *plaster of Paris* is produced. If this white powder be moistened, it again takes up the water of which it was deprived and sets in a solid mass having the same chemical composition as the original gypsum. The common name of barytes is *heavy spar*, in allusion to its high specific gravity (4·6). It is a fairly abundant mineral. Epsomite is the Epsom-salts of the druggist, and the bitter solution formed by dissolving it in water is familiar to many.

Compounds of Metals with Chlorine and Fluorine.—

Name of Mineral.		Chemical Name.		Chemical Formula.
Rock-salt	=	Sodium chloride	=	$NaCl$
Sal ammoniac	=	Ammonium chloride	=	$(NH_4)Cl$
Fluor-spar	=	Calcium fluoride	=	CaF_2
Cryolite	=	Fluoride of sodium and aluminium	=	$3NaF + AlF_3$

Rock-salt is by far the most important and abundant of these minerals. It generally occurs associated with anhydrite and gypsum. Sal-ammoniac is only found native in volcanic districts. Fluor, or fluor-spar, is the most important compound of fluorine, and is very widely distributed in nature. Unlike the two preceding haloid salts, it is insoluble in water. Cryolite is one of the chief sources of aluminium, and occurs abundantly in Greenland.

Sulphides are binary compounds containing Sulphur.—A few of the commonest sulphides are given below:—

Name of Mineral.	Chemical Name.	Chemical Formula.
Iron-pyrites ...	Sulphide of Iron ...	FeS_2
Galena	" of Lead ...	PbS
Blende	" of Zinc ...	ZnS

Iron-pyrites is a very common mineral, and is chiefly used for the manufacture of sulphur. It gives the dark blue colour to the limestone in the West of England, and many other rocks. Galena is the only important ore of lead. Blende is one of the chief ores of zinc. Neither galena nor blende are nearly so common as pyrites.

Oxides are binary compounds containing Oxygen.—With a few exceptions, all the elements in the crust of the globe occur as oxides. These compounds may not make up the mass of a rock, but they are nearly always present. Some of the chief metallic oxides are as follows:—

Name of Mineral.	Chemical Name.	Chemical Formula.
Magnetite ...	Black Oxide of Iron ...	Fe_3O_4
Cassiterite ...	Tin Dioxide	SnO_2
Hæmatite ...	Red Oxide of Iron ...	Fe_2O_3
Corundum ...	Oxide of Aluminium ...	Al_2O_3
Limonite ...	Brown Oxide of Iron ...	$2Fe_2O_3,3H_2O$

Magnetite is one of the most widely distributed minerals and the most valuable iron ore, containing about 72 per cent. of the metal. It is attracted by a magnet, and is frequently so permanently magnetic as to set in a north and south line like a compass needle, if pivoted or suspended by a thread. This quality gives the mineral the name *lodestone*. Cassiterite, or tinstone, is the only important tin ore, and contains about 79 per cent. of the metal. It occurs in granite, and also in river deposits, formed by the decomposition of this rock. In this case it is known as stream-tin. Hæmatite is a very important and abundant iron ore. A crystallised variety is known as *specular iron ore* and it also occurs massive, that is, in masses composed of a large number of crystals, as *red hæmatite*, of which red ochre is an impure variety. Corundum is chemically similar to hæmatite, and pure crystals of it are very valuable. The red ruby and blue sapphire are corundum crystals, probably coloured by the presence of chromium oxide. The emery largely used as a polishing material consists of very impure corundum stained with an oxide of iron.

Limonite, or brown hæmatite, is a hydrated iron oxide, that is, one containing water (about 15 per cent.). Nevertheless, it is an important iron ore, and furnishes excellent metal. *Gothite*, *turgite*, and *timnite* are also hydrated iron ores, having a similar chemical constitution to limonite.

Native elements are those which occur in Nature free or uncombined.—Of the 68 elements now known, the following are found native:—Carbon (as in diamond and graphite), sulphur, iron, copper, silver, gold, platinum, palladium, tellurium, lead, tin, mercury, arsenic, antimony, and bismuth. Some of these, however, are of very restricted occurrence.

QUESTIONS ON CHAPTER IX.

1. Name two elements present in greatest abundance in the earth's crust. State what you know about the nature of these elements. In what conditions do these elements exist in the earth's crust? (1890.)

2. Name five very common rock-forming minerals, and state what chemical elements are present in each of them. (1889.)

3. What is the binary compound which occurs in the greatest abundance in the earth's crust and of what elements is it composed? What minerals consist of this substance, and with what other binary compounds is it found united? (1888.)

4. Name four binary compounds of common occurrence, and state the elements of which each is composed. (1887.)

5. State what you know concerning the form and composition of a crystal of quartz. (1886.)

6. What is silica? What name is given to silica in the crystallised form? With what substances is silica found combined in the earth's crust? (1884.)

7. Name the minerals which occur in a piece of granite, and describe their chemical composition. (1879.)

8. Name four of the most common minerals which enter into the composition of the earth's crust and state the elements of which each is composed. (1878.)

9. State, in the order of their relative abundance, the eight chemical elements which enter most largely into the composition of rocks. (1877.)

CHAPTER X.

CLASSIFICATION OF ROCKS ACCORDING TO THEIR NATURE AND ORIGIN.

Classification of Rocks into Stratified and Unstratified.—An examination of the rocks that make up the

Fig. 91. Stratified Rock. (*From a Photograph by* Wilson of Aberdeen.)

earth's crust shows that they can be divided into two great classes. (1) Those that lie in more or less parallel layers, as sandstone, clay, limestone, shale, &c., are called Stratified, Sedimentary, or Aqueous Rocks, the last two names signifying that they were formed by the deposit of matter once suspended in water. (Fig. 91.) (2) Those that are unstratified and show evidence of once having been in a melted state, such as basalt and granite, are called Unstratified or Igneous Rocks. We shall first consider the latter class.

Distinguishing characteristics of Igneous Rocks.—Nearly all stratified rocks rest on igneous rocks, and it is only in a few districts that the latter are found at the surface. Igneous rocks occur in Cornwall, Wales, and Scotland, in masses of some extent, and form the rugged hills and crags which make the scenery of these places so picturesque. But other parts of Britain only contain fragments here and there, which apparently have been transported from other parts in past ages. Igneous rocks exhibit no true signs of having been deposited in layers. They have every appearance of rock which has been melted and forced up from the interior of the earth just as lava and dust are thrown out during volcanic eruptions at the present time and by cooling and pressure get hardened into rock masses.

Volcanic and Plutonic Rocks.—During a volcanic eruption immense quantities of melted rock are thrown into the air with escaping steam and various gases. Much of the ejected material, known as *volcanic ash*, is extremely fine. This, mixed with the condensed steam which falls as rain, forms a mud which eventually becomes a hard rock known as volcanic *tuff*. The rough cindery-looking fragments ejected are termed *scoriae* or *lapilli* according as they are large or small. Streams of melted rock called lava also flow from the sides and top of a volcano in action, and gradually cool down and consolidate into rock. Under some conditions (see p. 217) clots of lava are shot out from a mass of molten rock, and drawn into fine threads, forming what has been termed Pelé's Hair by the natives of Hawaii, where it is abundantly produced. Volcanic ash and lavas which have been sent out from volcanoes in this manner form *volcanic rocks* when they solidify. The melted rock in what may be called the reservoir of a volcano, cools much slower than that in contact with the outer air, and is subjected to a far greater *pressure owing* to its position deep down in the earth. These

conditions are favourable to the development of crystals, hence the minerals in such rocks separate out in the crystalline form. Deep-seated igneous rocks, or *plutonic rocks*, are therefore distinguishable from volcanic rocks in being distinctly crystalline in structure. The difference between the two classes is brought about by difference of position at the time of solidification. Utilising this fact of crystallisation, igneous rocks are divided into two great classes termed *crystalline* and *fragmental*.

Rocks belonging to the first of these classes are built up of numerous crystals, those of the second class are made up of broken fragments of all sorts and sizes. The crystalline igneous rocks may be sub-divided into those in which no definite arrangement of the crystals occurs (*e.g.*, granite), and those in which the crystals are arranged in more or less parallel lines, known as schistose rocks. In granite the crystals are large enough to be seen with the naked eye, but in many rocks they are only visible with the aid of a lens. The fragmental igneous rocks are exemplified by the material thrown out during a volcanic eruption and afterwards consolidated.

The Substances present in lavas are mainly silicates of aluminium, magnesium, calcium, iron, sodium, and potassium. The silicates are salts formed by the combination of the acid silica (the 'oxide' of silicon) with 'oxides' of these metallic elements, such compounds being bases. Oxygen, therefore, is an abundant element in lavas, and, as a matter of fact, it forms about 50 per cent. of the weight of all of them. Silicon generally makes up about 25 per cent. of the weight of lavas. Silica is always present, but the proportion varies from 60 to 80 per cent. in acid lavas such as trachyte, to about 50 per cent. in lavas such as basalt.

Igneous rocks may be divided, according to their chemical composition, into acid, intermediate, basic, and ultra basic.—Igneous rocks always contain silica in combination with different bases, and the proportion in which it occurs furnishes a means of classification. It will be remembered that silica, being an oxide of a non-metallic element, plays the part of an acid and combines energetically with metallic oxides such as alumina, soda, and lime. Rocks containing a high percentage are known as *acid*, those in which the percentage is low are known as *basic* rocks; rocks between these two extremes are termed *intermediate*. As a rule the specific gravity of acid rocks is less than that of intermediate

ones, and less in these than in basic rocks. The following are examples of this :—

Character.	Name.	Specific Gravity.
Acid	Granite	2·65
Intermediate	Syenite	2·80
Basic	Gabbro	2·95

The classification of igneous rocks according to their chemical composition is perhaps the best method. We thus get the arrangement shown in the following table :—

TABLE OF IGNEOUS ROCKS.

	Structure.	Acid Rocks.	Intermediate Rocks.	Basic Rocks.
Plutonic	Granitic	Granite	Syenite	Gabbro
			Diorite	Dolerite
Volcanic	Lavas	Liparite or Rhyolite	Trachyte	Basalts
		Obsidian	Andesite	Tachylyte
	Fragmental	Pumice	Pumice	Scoriae
		Rhyolite Tuff	Trachyte and Andesite Tuff	Lapilli
		Ash	Ash	Pelé's Hair
				Ash

Characteristics of Acid Rocks.—These rocks contain, on the average, from 70 to 75 per cent. of silica in combination with the bases alumina, potash, soda, etc. They generally contain mica as muscovite, but biotite, the black variety, is sometimes found. Rocks entirely made up of crystals are termed *granitic*, because of the similarity of their structure to that of granite. Common granite is, as we have seen, made up of quartz, felspar, and mica. The quartz is generally colourless; the felspar mainly occurs as orthoclase, and varies in colour from red and pink to white. The mica is sometimes found as muscovite in enormous quantities, but biotite is occasionally present. In some cases the mica is replaced by hornblende, and the rocks are then known as 'hornblende granites.'

Rhyolites are lavas consisting of similar materials to those of granite (which they much resemble), but in all of them the rock base contains some vitreous or glassy substance. *Obsidian* is a *glassy lava* possessing a perfectly vitreous lustre, and *Pitchstone*

a similar rock in which the lustre is dull or semi-vitreous. Obsidians and pitchstones, like pumice, occur both as acid and intermediate rocks, and to distinguish them they must be analysed or have their specific gravities determined.

Intermediate Rocks.—In intermediate rocks silica is present in the proportion of from 55 to 66 per cent. The proportion of alumina is the same as in basic rocks (about 15 per cent.), but the alkalis are smaller in quantity. Muscovite is seldom found in these rocks, and quartz is not an essential constituent of them. *Syenite* is a rock built up of crystals of orthoclase and hornblende or mica (as biotite); but, unlike granite, it contains no quartz. In some cases, however, quartz occurs as an accessory mineral, and the hornblende is replaced by augite. *Trachytes* consist of orthoclase set in a matrix or ground mass containing glassy matter. They can only be distinguished from obsidians by a chemical analysis, and by the determination of their specific gravity. *Diorites* or greenstones are composed of soda-felspar and hornblende, and present every gradation between the vitreous types of rocks and those entirely made up of crystals. *Andesites* are the lavas corresponding to diorites. They are very common igneous rocks, and are called hornblende-, mica-, augite-, or quartz-andesites according to their constitution.

Basic Rocks.—These rocks have a high specific gravity (from 2·7 to 3). They only contain about 50 per cent of silica. The proportion of alumina does not differ much from that in the two previous groups. Plutonic rocks of the basic group are known by the general name of *Gabbro*. Their structure is like that of granite—wholly crystalline—although the constituent minerals are different. These minerals are lime-felspar, and augite, which is very often altered to diallage. Olivine is generally present; indeed this mineral is almost as characteristic of basic rocks as quartz is of the acid group; and magnetite is of frequent occurrence. *Basalts* are the lavas corresponding to gabbro, and the rocks intermediate between the two are called *Dolerites*. These have not a perfect granitic structure like gabbro, nor do they usually exhibit the black granular appearance of basalt. The crystals of augite and felspar in them are visible to the naked eye. Where a basic rock has cooled rapidly in contact with another, a black glassy film known as *Tachylyte* is formed, which differs from obsidian in having a higher specific gravity, and in being easily fused.

Ultra-Basic Rocks include those characterised by a very

low percentage of silica (35 to 45 per cent.), and a very high specific gravity (3 to 3·8). They have approximately the same composition as stony meteorites, and from them we get an idea of the constitution of the great mass of the interior of the earth's crust.

Aqueous rocks are derived from the decomposition of Igneous rocks.—We have previously shown that granite, an igneous rock, is composed of quartz, orthoclase (silicate of potash and aluminia), and mica. The silicate of potash is easily decomposed, and the sulphates, chlorides, and carbonates which are formed soon get washed away. Silicate of aluminium is not so easily broken up, but has a tendency to take up water and thus become a hydrated silicate. The quartz when disintegrated forms sand grains. We, therefore, get two insoluble substances produced by the decomposition of granite, viz., silicate of aluminium and sand grains, and these give rise to the two classes of aqueous rocks known as argillaceous and siliceous. The soluble portions give rise to calcareous rocks.

Classification of Aqueous rocks.—The following table exhibits a division of the aqueous rocks according to their mode of formation. It also shows the rocks which are siliceous, argillaceous, or calcareous, that is, those which consist mainly of silica, clay, and lime respectively:—

TABLE OF AQUEOUS ROCKS.

	Siliceous.	Argillaceous.	Calcareous.
Mechanically-formed Rocks.	Gravels Sands Sandstones Grits Siliceous Conglomerates " Breccias	Mud and Silt Clay Shale	Shell and Coral Sand
Chemically-formed Rocks.	Flint and Chert	Kaolin	Calcareous nodules and concretions Stalactites and Stalagmites
Organically-formed Rocks.	Polishing Slate (Tripoli powder) Sinter Travertine		Calcareous Ooze Coral Reefs Oolitic and other Limestones Chalk

Clay is a hydrated Silicate of Alumina.—*Kaolin*, the purest kind of clay, has a tolerably definite chemical composition, expressed by the formula (Al_2O_3), $(2SiO_2)$, $(2H_2O)$. It is chiefly derived from granite by the decomposition of felspar in the manner indicated before. Clay possesses the remarkable property of becoming plastic when wetted, and so can be moulded into any desired shape. Its ability to hold water is well known. *Fire-clays* contain a certain amount of free silica, and are infusible.

Shale is compressed or hardened clay, which may be split up into thin layers or laminæ along the lines of stratification or bedding. A distinction between clay and shale is that the latter contains carbonaceous matter.

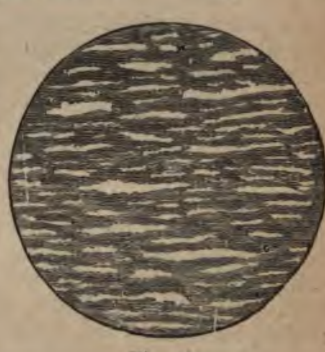


Fig. 92.
A fragment of slate cut into a thin slice and highly magnified.

Slate, or *clay-slate*, has nearly the same composition as clay and shale. It differs from these in the important fact that it splits into laminæ along totally different lines to the lines of stratification. (Fig. 92.) This difference indicates that the cleavage is a structure induced upon the rock after it had been deposited. Some experiments have been made which prove that cleavage can be caused by pressure. A mass of pipe-clay, throughout which micaceous particles were

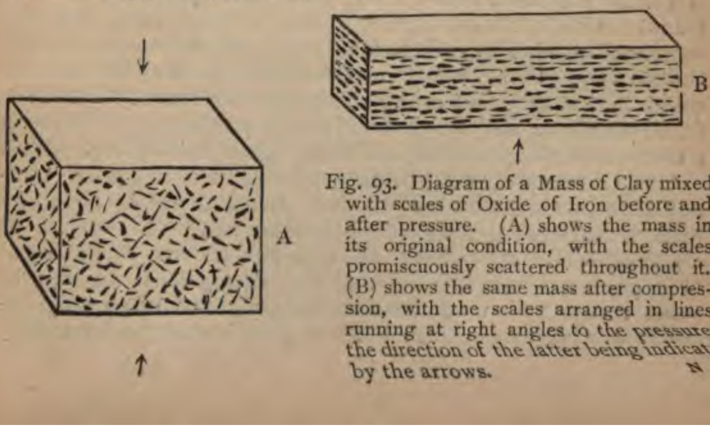


Fig. 93. Diagram of a Mass of Clay mixed with scales of Oxide of Iron before and after pressure. (A) shows the mass in its original condition, with the scales promiscuously scattered throughout it. (B) shows the same mass after compression, with the scales arranged in lines running at right angles to the pressure, the direction of the latter being indicated by the arrows.

distributed, was subjected to pressure so that it was flattened. It was then found that the particles were all arranged at right angles to the direction of the pressure, and that the mass could be split in this direction, whereas previously there was no definite arrangement, no tendency to split along any particular lines. (Fig. 93.)

Loam and **Silt** are unconsolidated mixtures of clay and sand.

Calcareous Clay or **Marl** is a mixture of clay, with a variable quantity of lime.

Sands are loose grains formed for the most part by the decomposition of granite and similar rocks.—Sands are of various colours, as every one knows, but if some grains be broken it will generally be seen that the colour is only skin-deep, and that the inside is colourless. In fact, sands consist mostly of clear quartz grains, and their red, yellow, or green colour is due to a thin coating of some compound of iron. The sands first formed by the disintegration of granite rocks are angular in appearance, and the different constituents—the clear quartz, dusky felspar, brown mica, and brown-green hornblende—can be easily distinguished under the microscope. On the other hand, sand grains from a desert, which have been blown about and rubbed together by the action of wind, are considerably rounded and polished. Water-worn sands have not the very rounded appearance usually ascribed to them.

Sandstone is consolidated Sand.—By pressure, and the deposition of some cementing material, sand grains are bound together and form a solid rock, sandstone, the colour of which depends upon the compound of iron which is present. Quartz is usually the main constituent, but felspar and mica are also found. *Calcareous* sandstones consist of fine sand particles, cemented together by carbonate of lime. *Argillaceous* sandstones contain clay. Some fine-grained varieties are more or less laminated, that is, they split in the planes of stratification. These are called *flagstones*, and are used for paving purposes. *Gritstone* is a coarse and siliceous rock, containing comparatively large grains.

Conglomerate, or pudding-stone, is a mass of consolidated gravel or shingle, the pebbles being rounded and water-worn, and set in some kind of matrix or cement.—The appearance of the pebbles in conglomerate (Fig. 94) is a certain indication of their having been rounded by water action, and, were the cementing material taken away, we *should evidently* have left a heap of gravel, such as form many

sea-beaches. The consolidation of a gravel-bed is caused by water slowly filtering through it and depositing carbonate of lime, iron oxide, silica, or a mixture of these compounds, upon the sand

Fig. 94. A piece of Conglomerate or Pudding Stone.

and pebbles, until the spaces between them are filled up. *Quartzose* and *Limestone* conglomerates consist chiefly of quartz and limestone pebbles respectively.

Breccia is a mass of large angular fragments cemented together in a similar manner to conglomerate.—Such rocks as these are formed by the consolidation of materials broken off from rocks by frost and other agencies.

Stalactites and Stalagmites.—The soluble substances produced by the disintegration of igneous rocks are generally much less in amount than those insoluble in water. Rocks are formed from such substances by chemical deposition or precipitation. Water containing carbon dioxide in solution has the property of dissolving limestone or carbonate of lime. Rain-water and spring-water always contain a certain quantity of this gas, and so always possess this property. Hence, when such water percolates through limestone it dissolves some of the calcium carbonate. If it reaches an underground cavern,—and many caverns are produced in limestone by water dissolving away this rock—some of the carbon dioxide escapes, and since the water cannot then hold as much calcium carbonate as at first, some is deposited as a white film and eventually a rod or tube of the material is formed. Such growths are called *stalactites*. When the water hanging from the end of a stalactite drops to the ground a further

evaporation takes place, the resulting growths known as *stalagmites* being formed. These growths increase in size until the two meet to form a column of stone. Such masses cover large portions of the floors of caverns, and are important geologically, as they seal up and preserve bones and other organic remains. The production of stalactites may be seen on the under surface of many arches, or on the vaulted roof of a cellar, the carbonate of lime being derived in these cases from the mortar.

One of the most beautiful stalactite caverns in England occurs in the carboniferous limestone cliffs of Cheddar in

Fig. 95. Part of a Stalactite Cave at Cheddar, Somersetshire. (*From a Photograph by Frith, with permission of Mr. Cox.*)

Somerset. It was accidentally discovered by Mr. Cox in 1839, and Elihu Burritt said of it:—'In delicacy of execution, its water sculpture far surpasses anything that I saw in the Mammoth Cave in Kentucky. The colours of the stalactites range through pale shell-like pinks and ambers, rich, warm, velvety browns, the colours of crusty loaves, and those of rusty iron and ochreish earth. Some of them when struck emit a series of musical notes, clear and mellow as those of silver bells, and at their points gleam like diamonds the pendant drops of the ever-falling water.' A general view of some of the formations to

be seen in the cavern is given in Fig. 95. One of the most beautiful objects is a stalactite with a serrated edge hanging from the roof in folds like a curtain. And with a slight exercise of the imagination it is possible to recognise the various forms pointed out by the guide. In one place a brown loaf, a mummy, a Hindoo temple, and in others a fat goose, turkeys, carrots, and a font filled with water may be distinguished. The stalagmites are from four to fifteen feet high, and their curious shapes, with those of the hanging stalactites, are reflected in the water on the floor of the cave, and furnish a picture of exquisite beauty.

Travertine, or calcareous tufa, is the name applied to the loose organically deposited carbonate of lime. It is largely found in Italy. Water, upon coming to the surface, after circulating through limestone in a volcanic region, contains carbonate of lime, and there is evidence that this is secreted and deposited by Algae. If this action continues for a long time beds of travertine are formed, which may fill up valleys or the basins of lakes.

Rock-Salt, or sodium chloride ($NaCl$) is found in beds of varying thickness. The greatest mass of rock-salt in the world occurs at Wieliczka in Austria. The salt mines of Cheshire are also well known. In a pure condition rock-salt is white, but usually it contains other chlorides mixed with clay, sand, &c., and is red, blue, green, or brown in colour. It was at one time dissolved in water contained in enclosed basins where the total amount of water supplied by springs or streams was less than that lost by evaporation. The saline matter thus accumulated and the saltness of the water therefore increased until the basin became filled with a solid deposit. The same process is going on in the Dead Sea, the Great Salt Lake of Utah, the Caspian Sea, and the Sea of Aral. A pound of water taken from the Dead Sea and carefully evaporated leaves behind a quarter of a pound of solid matter, which is about seven times the amount found in ordinary seawater. In like manner, a pound of water from the Great Salt Lake leaves $2\frac{1}{2}$ ounces of solid matter. There is therefore no difficulty in understanding how enormous masses of rock-salt were formed by the slow evaporation of the bodies of water which originally contained it in solution. On account of its solubility in water rock-salt is only found near the surface in very dry countries. Generally speaking, in passing down from the surface to a formation containing the salt, one would first arrive at a mass which, being reached by

water from the surface, exists in a semi-liquid condition. This is pumped to the surface as brine and evaporated to procure the salt. After this a bed of red marl may occur, and then the proper rock-salt is found in a very firm and well crystallised condition. This is not reached by surface water and is worked in chambers with pillars left to support the roof.

Glauconite Marl.—In some cases shells of foraminifera (minute marine organisms) are more or less filled with glauconite —a hydrous silicate of iron, potash, and alumina. If the shells are dissolved away by means of a weak acid the greenish-coloured silicate is left in the form of casts of their interior.

Flint and Chert are concretions which frequently contain shells, sponges, &c., round which they formed on the sea-floor. The former mineral occurs in no rock but chalk. In some cases the calcareous shells are entirely replaced by siliceous materials, silica being gradually substituted for the original carbonate of lime.

Gypsum, or calcium sulphate ($CaSO_4$), occurs in beds usually associated with red-clay, rock-salt, or anhydrite, and sometimes with dolomite. It is mainly produced, like rock-salt, by precipitation from solution in water. When a portion of sea-water is evaporated the first substance given up is gypsum, hence it is the first mineral deposited on the floors of salt lakes and inland seas.

Dolomite occurs in massive beds as magnesian limestone, although the relative proportions of the carbonates of calcium and magnesium vary considerably. It is formed by the evaporation of water containing saline matter in solution, and is, therefore, generally associated with rock-salt and gypsum.

Sinter is a variety of silica deposited around many hot springs, such as are found in the Yellowstone Park of the United States and New Zealand. Evidence has recently been brought forward that sinter is an organically-formed rather than a chemically-formed deposit.

Other chemically-formed minerals are hæmatite, magnetite, and other iron-ores, which occur mixed with clay, sandstone, shale, limestone, etc., and have generally been deposited on the floors of lakes or beneath marshy ground.

Metamorphic aqueous rocks are those which have had their structure more or less altered since they were originally deposited.—We have stated that aqueous *or sedimentary rocks* are produced by the crumbling away of

igneous rocks. As the layers of sediment accumulate those first deposited are buried deeper and deeper. They, therefore, are subjected to enormous pressures and high temperatures, and these, acting for a long period, cause changes of structure and composition to take place, the resulting production being rightly termed metamorphic rocks. Metamorphism is also produced by the passage of masses of heated lava through sedimentary rocks. Metamorphic rocks are sometimes so highly crystalline that they cannot be distinguished from igneous rocks. Indeed, it is probable that there is a complete sequence of changes from igneous to sedimentary rocks, and from sedimentary to igneous again through metamorphic rocks. If this be true, the materials of the earth's crust may have undergone the transformation several times.

Slates are argillaceous rocks showing cleavage-structure.—Slate is mainly a hydrated silicate of alumina, like shale and clay. It was originally deposited in layers, and was then capable of splitting in the planes of bedding. The cleavage-structure was produced by the action of great lateral or side pressure whereby the particles were re-arranged so as to have their longer axes perpendicular to the direction in which the compression had taken place. There is always a tendency for certain minerals to develop in slates, hence we find mica, talc, clay, and chlorite-slate, the long axes of the minerals being parallel to the planes of cleavage. Sometimes clay or shale has been converted by heat into a splintery rock without cleavage, called *Hornstone*.

Schists, or foliated rocks, consist of crystalline minerals arranged in separated 'folia' or leaves.—Schists differ from ordinary stratified formations in the following important characteristics:—(1) The layers are made up of different *minerals* and not different *rocks;* (2) The 'leaves' of mineral matter can usually only be traced for an inch or two, whereas strata can generally be discerned for a considerable distance. Rocks having this appearance are called 'schists,' or are said to have a 'schistose' structure. It is usual, however, to use the former word as a suffix to the names of the minerals of which a foliated rock is mainly composed. Thus, *Mica-schist* consists of alternate irregular layers of muscovite and quartz; the mica generally formed of a number of small plates firmly compacted together, and the quartz more or less resembling vein-quartz; many varieties only contain a little quartz. It often has

a minutely corrugated or crumpled structure. *Quartz-schist* is chiefly quartz with a small quantity of mica, and *Hornblende-schist* is made up of quartz and hornblende. *Talc-schist* occurs with talc in foliated layers and quartz, often in the form of nodules. Since the foliation and re-crystallisation must have been produced after the deposition of those minerals, the rocks in which they occur are truly metamorphic sedimentary rocks.

Gneiss is a foliated rock containing felspar (mostly orthoclase), mica, and quartz.—Mica-schist thus merges into gneiss by the addition of felspar. Gneiss mainly differs from granite in the fact that the constituent minerals are not scattered indiscriminately through the mass, but are arranged in irregular lenticular layers or 'folia' similar to those just described. Gneisses are frequently made up of granules arranged more or less in layers. They are then said to be 'granulitic,' and are rich in quartz and poor in mica. In *granite gneiss* the foliated arrangement is often unrecognisable, and in some granites slight traces of foliation may be seen round the edges. These intermediate rocks, therefore, connect the metamorphic with those of igneous origin.

Quartzite is a hard, fine-grained rock, formed by the re-crystallisation of a sandstone.—Quartzite, when microscopically examined, is seen to be made up of grains of quartz-sand, a schistose structure being developed in the mass by variable quantities of felspar, mica, talc, etc. The interstices between the grains have been filled up by silica, probably produced by the action of heated water upon the quartz, and afterwards deposited. This is supported by the fact that the grains seem to run into each other.

Marble is crystallised carbonate of lime (limestone) having a fine-grained structure.—Pure marble is white. There are, however, numerous varieties, of different colours and textures. A thin slice of marble when magnified is seen to consist of granules of calcite. Any impurities which may have existed in the limestone before the change was brought about re-crystallise with the carbonate of lime, and become arranged in the different coloured streaks which so commonly occur in marble.

Crystalline dolomite is very similar to crystalline limestone.

QUESTIONS ON CHAPTER X.

1. What are lavas? Of what chemical elements are lavas chiefly composed? (1888.)

2. How are conglomerates formed? (1885.)

3. In what respect do slate and shale respectively differ from clay? (1881.)

4. How is kaolin derived from granite? Describe the several stages of the process. (1880.)

5. Of what materials are clay, shale, and slate chiefly composed, and in what respects do these rocks differ from one another? (1877.)

6. How are igneous rocks classified according to their chemical constitution? Give an example of each class.

7. How are sands and sandstones formed?

8. What are stalactites and stalagmites? Describe their mode of formation.

9. What are metamorphic rocks? How are they formed? What are the characteristics of mica-schist and gneiss?

CHAPTER XI.

ROCKS OF ORGANIC ORIGIN; THEIR STRUCTURE, COMPOSITION, AND MODE OF FORMATION.

The chief chemical elements found in plants and animals are carbon, hydrogen, oxygen, and nitrogen. Plants obtain the carbon from the carbon dioxide (CO_2) in the atmosphere, and oxygen and hydrogen from water (H_2O). Nitrogen is taken from the atmosphere by the leaves, and from the soil by the roots. Plants have the power of transforming these elementary substances into the complicated ones required for their existence. Animals are unable to do this, and are thus dependent upon plants for the constituents necessary to build up their frames. During life plants evolve oxygen and retain carbon dioxide, water, ammonia (NH_3), and various inorganic salts; animals take and use up oxygen from the atmosphere, and evolve carbon dioxide, water, and other oxidised products. The first substances commonly formed when vegetable and animal matter decay are

ammonia, carbon dioxide, and water. These are returned to the atmosphere. The soluble salts in the organism are then dissolved away and diffused among the water of our globe. Chemically speaking death is but a change of complex into simpler substances. This is well put by Professor Huxley, in his 'Lessons in Physiology,' as follows:—'The sun's rays, acting through the vegetable world, build up some of the wandering molecules of carbonic acid, of water, of ammonia, and of salts, into the fabric of plants. The plants are devoured by animals, animals devour one another, man devours both plants and other animals; and hence it is very possible that atoms which once formed an integral part of the busy brain of Julius Cæsar may now enter into the composition of Cæsar, the negro, in Alabama, and of Cæsar, the house-dog, in an English homestead.'

Some plants possess the property of separating calcium carbonate from water containing it.—The plants which have this property belong to the Algæ group, and include sea-weeds and such fresh water plants as live exclusively under water. Many of these plants become quite stony in character, in consequence of the absorption of calcium carbonate into their tissues. Others do not precipitate the carbonate within their cell walls, but become coated on the surface only with a white amorphous crust of the material. Chalk, and the white mud brought up from a part of the Atlantic having a depth of about 2,000 fathoms, contain a large number of minute calcareous bodies, called *coccoliths*. Occasionally these unite to form spheroidal masses termed *coccospheres*. Whether they are the remains of plants or animals is not definitely known, but in all probability they belong to the former.

Animals which separate carbonate of lime from water containing it.—In both the plant and animal kingdom the lowest forms of life separate the highest proportion and greatest quantity of lime from the water in which they live. The *Protozoa* —one of the lowest forms of animal life—consist merely of a small jelly-like nucleus, surrounded by a cell. Two varieties of this group, called the *Foraminifera* and *Radiolaria*, are of great importance. The skeletons of the former are composed of calcium carbonate, whilst those of the latter consist of silica. Most of the foraminifera are only about the size of a pin's head, but they occur in such great numbers in the Atlantic and other seas that their skeletons after death form immense beds of rock

at the bottom. (Fig. 97.) Foraminifera mostly contain numerous holes in their cells or shells, through which the jelly-like matter of the interior projects in thread-like arms in search of food. These separate the calcium carbonate in the form of calcite. Some have only a single hole. These separate the same material in the form of arragonite. And since calcite is not so easily dissolved as arragonite more skeletons are found composed of the former substance than of the latter.

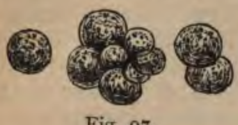


Fig. 97.
Globigerina, a genus of Foraminifera, from the bottom of the Atlantic. Magnified about 25 times.

Plants which separate silica from fresh and sea water. —Some siliceous rocks—for example, that which furnishes the polishing powder from Tripoli (Tripoli powder)—are formed of

Fig. 98. Microscopic Section, showing diatoms.

material originally separated from solution by organisms. Diatoms, which constitute one of the most minute and interesting forms of plant life, are amongst the most active agents in secreting from

water the very small proportion of silica which is held in solution in it. Though the largest of them are only barely visible to the eye, yet their fossil remains have formed extensive beds of great thickness in various places. The deposits formed by the remains of these plants are found at the old bottoms of lakes, and on the sea-floor. In Richmond, Virginia, there are extensive tracts, covered with a thickness of about 40 feet of this diatom-earth, and other deposits occur at Monterey, Franzenbad, Bermuda, and Loch Morne (Ireland). Fig. 98 is a microscopic representation of the siliceous shells of diatoms seen after the organic and earthy matter in which they occur have been removed by an acid.

Radiolarians or Radiolaria are animals which separate silica from sea-water.—The radiolaria differ from the diatoms in the fact that they are all marine, and occur probably in only the deepest parts of the ocean. (Fig. 99.) The thread-like portions which protrude from their siliceous cells do not interlace, as is often the case with those of foraminifera, but radiate in straight lines. But the great difference between the two lies in the fact that one has a siliceous and the other a calcareous skeleton. A deposit of radiolarian earth occurs at Barbadoes, and this, when treated with an acid and viewed microscopically, is seen to be composed of the siliceous shells of radiolarians similar to those found more or less abundantly in all deep sea deposits. Another class of animals, known as siliceous sponges, also have the power of separating silica from sea-water to form long needle-like bodies called *spicules*. When the organism dies the spicules are left, and, in combination with diatomaceæ and radiolarians, furnish the siliceous materials which cover extensive areas of the bottom of the ocean.

Fig. 99.
Radiolaria, from the bottom of the Atlantic. Magnified about 100 times.

Coral is a calcareous formation consisting mainly of the skeletons of an organism termed the coral-polyp.—Some of the incorrect ideas which prevail in the popular mind *with regard to* the growth of coral are dispelled by the following

extract from Prof. James D. Dana's standard work on the subject.

'It is not more surprising, nor a matter of more difficult comprehension, that a polyp should form structures of stone (carbonate of lime) called coral, than that the quadruped should form its bones or the mollusc its shell. The processes are similar, and so is the result. In each case it is a simple animal secretion—a secretion of stony matter from the aliment which the animal receives, produced by the parts of the animal fitted for this secreting process, and in each, carbonate of lime is a constituent, or one of the constituents, of the secretion.

'The power of secretion is then one of the *first* and most common of those that belong to living tissues; and though differing in different organs according to their end or function, it is all one process, both in its nature and cause, whether in the animalculæ or man. It belongs eminently to the lowest kinds of life. These are the best stone-makers; for in their simplicity of structure they may be almost all stone and still carry on the processes of nutrition and growth. Throughout geological time they were the agents which produced the material of limestone, and also to make even the flint and many of the siliceous deposits of the earth's formations.

'Coral is never, therefore, the handiwork of the many-armed polyp; for it is no more the result of labour than bone-making in ourselves. And again, it is not a collection of cells into which the coral animals may withdraw for concealment any more than the skeleton of a dog is its house or cell; for every part of the coral—or corallum, as it is now called in science—of a polyp, in most reef-making species, is enclosed more or less completely within the polyp, where it was formed by the secreting process.'

The poetic supposition that coral polyps work and build up masses of rock as bees construct the honey-comb, or ants their hillocks, must therefore be abandoned as erroneous.

Coral is made by four kinds of organisms, viz.—(1) Algæ, or seaweeds; (2) Bryozoans, the lowest kind of mollusc; (3) Hydroids, animals related to the fresh water Hydra, and (4) Polyps. The last of these are by far the most important producers of coral-reefs at the present time.

The appearance of a polyp is very similar to that of a garden aster. (Fig. 100.) The flower consists of a coloured centre, round which are arranged rows of tinted petals. The common form of a polyp is that of a disc with organs termed tentacles radiating

from its edge like the petals of the flower. But the analogy must not be carried further, for whereas the aster flower is supported by a slender stem, the disc and tentacles of a polyp are situated on the top of a cylindrical body containing the stomach and often

Fig. 100. Dendrophyllia Ramea, one of the 'Tree Corals,' showing the little cups in which the polyps live (half natural size).

having the same diameter as the disc at the centre of which the animal's toothless mouth is found. The mouth of a polyp is thus very conveniently arranged, for it opens directly into the *stomach.*

The internal structure of a polyp is represented by the cross-section shown in Fig. 101. The white radiating lines consist of the calcareous (coral) skeleton around which occur fleshy portions of the animal. The carbonate of lime deposited to form the radiating partitions becomes attached to the rock, and as the polyp grows upwards and outwards a more or less cylindrical stem is produced, which in many cases is quite solid owing to the filling up of the interior. It has already been remarked that the polyp mounts upwards on the coral. Obviously, then, the animal must either stretch out as the solid secretion accumulates, or it must exist only on the top portion of the cylindrical stem. The latter is what really occurs. A polyp a quarter of an inch or so in length may exist on the top of a self-constructed base many inches high. And so long as the animal lives it increases the height of the dead coral monument upon which it is pinnacled.

Fig. 101.
Cross-section, showing the internal structure of a coral polyp.

Coral-polyps multiply by budding.—In this respect the polyps follow a process very similar to that of many plants. A slight prominence will appear at the side of a polyp; this enlarges, and eventually a mouth and a fringe of tentacles are produced as in the parent. The young and fixed polyp gets its living, and secretes carbonate of lime to form a stem or flat surface connected with that of the parent. It, in turn, produces buds and so on *ad infinitum*, until a mass of coral many feet or yards broad or long is formed from a single germ. Sometimes polyps multiply by subdivision, that is to say, a single polyp will divide into two and thus bring about an increase of population, so that finally a fragment of a polyp may form the beginning of another coral growth as large as that of the animal from which it was separated.

Coral Reefs are ridges or banks of rock composed almost entirely of pure limestone, found in certain parts of the ocean. Sometimes they occur as rings of various sizes, many being several miles across, surrounding a lagoon of sea-water. These islands, known as 'atolls,' are common in the warm parts of the Pacific and Indian Oceans. Sometimes the coral-rock forms a kind of natural breakwater at some distance from land. These 'Barrier-reefs' run more or less parallel to the shore and are

separated from it by a broad channel of comparatively shallow water. A great barrier reef runs outside the north-east coast of Australia for a distance of 1,200 miles, its average distance from the shore being about fifty miles. Similar formations completely surround many islands in the Pacific, and are termed encircling reefs. 'Fringing reefs,' as the name implies, are low banks or ridges of coral rock running along close to some shore. Atolls consist of, (1) Living coral at the surface and sides, and, as the polyps thrive best in a heavy surf, they grow faster on the outside than inside of the ring of rock; (2) Remains of coral and other calcareous organisms; (3) Coral sand, and mud formed by the grinding together of pieces of coral broken off by the waves; (4) Coral changing into crystalline limestone in the interior of the rock. Winds and ocean currents bring seeds to atolls, and so eventually the coral becomes covered with vegetation and may become the abode of man. (Fig. 102.)

Fig. 102.
Plan of an Island surrounded by Coral Reef.

Reef-building corals are those whose skeletons build up *reefs* or ridges of coral rock in the sea. Sometimes islands or rings of rocky land are composed to a large extent of this material. But although these formations may rise from a considerable depth below sea level, the dead coral only has a height of 10 or 12 feet above it. The conditions under which reef-building corals flourish are, (1) A temperature not below 68° F.; (2) Any depth from low-water level to about 25 fathoms; (3) Clear and constantly moving water. On account of the last named circumstance reef-building corals will not live near the mouths of large rivers, for the water is too full of sediment. They grow best on the seaward side of a reef, the reason being that there is a better supply of food on the outer than on the inner side. And whilst the rough surf is favouring the growth of the reef outwards, the water of the interior is gradually dissolving

away the piled up material, and contains few live polyps. Since reef-building corals require water having a tropical temperature, they are confined to latitudes between about 25° N. and S. of the equator. A line of reefs and islands extends from the Caroline Islands to the Low Archipelago in the Pacific; and in the Indian Ocean between Madagascar and India. Other corals are found in most seas, but they do not form reefs.

Mode of formation of Atolls and barrier and fringing Coral Reefs.—Reef-building corals cannot live below a depth of about 25 fathoms (150 feet). This has been proved by letting down grappling irons, and bringing up masses of coral rock. That dragged up from a depth of 120 feet or less contained living polyps, but in masses from a greater depth they were for the most part dead. And since coral rock, built of the remains of reef-building corals, is found at very great depths, some explanation of this fact is necessary. Charles Darwin accounted for the fact by the gradual sinking of parts of the ocean bottom. According to this hypothesis a fringing-reef is first formed around an island. As the island sinks the coral formation grows upwards by the deposition of calcareous remains, and so eventually a barrier reef, that is, one separated from the shore by a wide channel of sea-water, is produced. Finally, the peak of the island disappears below sea-level, and the ridge of coral rock rises above in a more or less circular ring surrounding a lagoon of sea-water, and forms an atoll. (Fig. 103.) Barrier reefs and atolls are therefore proofs of the subsidence of the

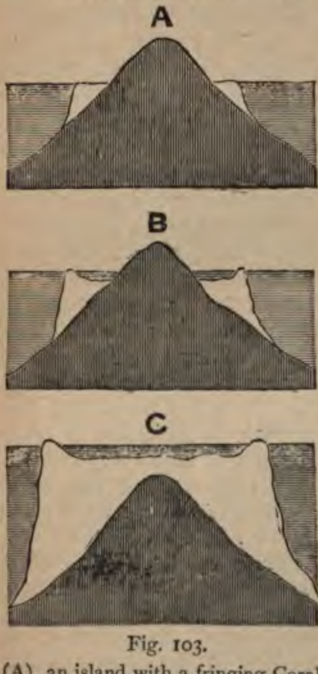


Fig. 103.

(A), an island with a fringing Coral Reef; (B) represents the stage in which it is surrounded by a Barrier Reef; and (C) when the island has given place to an Atoll.

part of the ocean floor on which they occur, if Darwin's theory as to their mode of formation is correct, and until recently the balance of evidence seemed in its favour. Another explanation put forward by Dr. Murray accounts for many of the facts also. It is that coral reefs are built up on sub-marine volcanoes whose summits have reached a point from 120 to 150 feet below sea-level. If the summit were really deeper than this to begin with, the accumulation of remains of organisms might bring it near enough to the surface for the reef-building corals to flourish upon it. An atoll would thus be formed by the growing upwards and outwards of the coral rock. By the continuation of the growth a fringing reef and then a barrier reef would be evolved. The latter would extend seaward on account of the outward growth, to which reference has been made, and so increase its distance from the shore. On Dr. Murray's theory, therefore, the wider the channel between a barrier reef and the coast line the greater is the age of the formation. One objection to the hypothesis is that it would require an enormous number of volcanoes, all of them to come near the sea-surface, but none to rise above it, to account for the numerous atolls, and this is rather an improbable occurrence. Darwin's theory, however, is also open to many objections, for it has been shown that some of the areas of land which should be sinking are really rising.

Organic rocks are those formed of the remains of plants and animals.—Most of the organic rocks are calcareous, that is, composed mainly of carbonate of lime. The simple compounds contained in this substance, and the mode of separating them, are described on p. 71. It is not necessary that hard parts of some dead organism should be detected in rocks of organic origin. One form of carbonate of lime (aragonite) is less durable than the other (calcite). Hence shells consisting largely of the former material might crumble down into a white amorphous mud, whilst those of the latter would be little altered. The fact that the specific gravity of calcite is about 2·72, whilst that of aragonite is about 2·93, serves to distinguish the two minerals. Aragonite is also much harder than calcite. But, obviously, whether the material has changed or not does not affect the fact that it was originally formed of the remains of organisms. Indeed, in many rocks of undoubted organic origin the organic structure is entirely obliterated.

***Chalk* consists chiefly of the skeletons and shells of *organisms which* possessed the property of secreting**

calcium carbonate, from water containing it.—If some powder rubbed off a piece of chalk be placed in water, and a little of the sediment which falls to the bottom after a short time be placed on a slip of glass and viewed under a microscope, the grains will be seen to consist of minute fragments of shells and other remains of organisms. The rock is evidently made up of materials which once formed parts of living things. (Fig. 104.) Now, if some of the white mud found at the bottom of the Atlantic be similarly examined, it will be seen to closely resemble the composition of chalk, although the two are not identically the same. Each deposit contains a number of Globigerinæ mixed with coccoliths, coccospheres, spicules of sponges, and similar materials; hence it is concluded that the origin of the two is similar, that is to say, the white chalk cliffs of our south-eastern coast, and the chalk hills of Wiltshire and other parts of England, were formed in past ages by the deposition of the skeletons and shells of dead organisms.

Fig. 104.

A thin slice of Chalk as seen under the microscope, showing that the rock is composed of minute shells (Foraminifera) imbedded in a granular basis of lime.

Coral-rock is a compact limestone formed by the consolidation of coral-mud or other remains of polyps.—A piece of coral has every appearance of being what it is—a formation produced by the accumulation of the skeletons of once living organisms. But coral-rock has no such distinct organic structure, and is very similar to the fine compact limestone found in the West of England and elsewhere. This difference in character may be brought about by different means. The intervals between corals may be filled up by water containing carbonate of lime in solution, which filters through them and deposits the material, or the action of the waves in grinding together and breaking up coral, may produce fine coral sand and mud, which, by pressure and deposition of carbonate of lime from the water, becomes consolidated into compact layers; just as sandstones are formed by the consolidation and cementing together of particles of common sand.

Limestones consist essentially of masses of carbonate of lime having generally an organic origin.—There are numerous varieties of limestone varying considerably from each other in their physical characteristics. Some are evidently built up of organic remains (Fig. 105), whilst others show no indications of such an origin. *Crinoidal* or *encrinital* limestone is composed mainly of the remains of jointed marine animals termed encrinites, mixed with those of foraminifera, corals, and molluscs. The organic structure of this rock is often preserved, and the jointed stems of the organisms can then be easily distinguished. (Fig. 106.) *Shell limestone* is that in which shell fragments are large and conspicuous. Common compact limestone generally exhibits no sign of having been organically formed. It has been consolidated by pressure and by the interspaces becoming filled with fine-grained mud or calcite deposited from water. *Hydraulic* limestone consists of a mixture of carbonate of lime with silicate of aluminium containing iron. After this has been burnt in a kiln and reduced to powder, it forms with water a hard cement which 'sets' under water, and is therefore used for cementing the piers of bridges, &c. Some limestones are siliceous, that is, they contain a relatively large proportion of silica. *Argillaceous* limestone contains a variable quantity of clayey matter. *Ferruginous* limestone is a mixture of carbonate

Fig. 105.

A thin slice of Limestone (Carboniferous), as seen under the microscope, showing that the rock is almost wholly made up of animal remains.

Fig. 106.

A small piece of Limestone, showing numerous fragments of Crinoids on its weathered surface.

of lime and carbonate of iron. *Magnesian limestone* is a mixture of carbonate of lime and carbonate of magnesia. Bituminous limestone is a black rock containing much carbonaceous matter. *Marble* is a limestone of a crystalline structure, and hard enough to be polished.

Oolite or Roe-stone consists of small round particles of carbonate of lime, arranged in successive concentric layers round some minute particle of foreign matter forming a nucleus.—The grains of oolitic limestones resemble somewhat the roe of a fish, hence the name. They have every appearance of having been produced by successive depositions of carbonate of lime round a particle of sand or similar body, and until recent years were considered as chemically-formed rocks. Evidence has been adduced, however, which indicates that many oolitic rocks are of organic origin. If a thin section of oolitic limestone be examined, the grains will be seen to be formed round fragments of shell, and subsequently cemented together by crystalline calcite. *Pisolites* are similar rocks in which the grains are about as large as peas.

Peat is composed of plants in a more or less compact and decomposed condition.—Over a large portion of Ireland and in many parts of England, Scotland, North America and other places marshy vegetable accumulations occur, termed *bogs* or *peat-mosses*. The bogs of Ireland were computed in 1819 to occupy 2,830,000 acres. The mosses which contribute most towards the accumulations are known by the general name of Sphagnaceæ, a group of comparatively few species and very marked organisation. Some parts of a peat-moss are so swampy that they will not bear a person's weight, while in others the surface is firmer and only trembles when he is picking his way over it. It is a matter of common knowledge that the peasantry living in many districts in Ireland and Scotland dig out the material of bogs, and after piling it into stacks to dry, use it for fuel. From the cuttings that are made to obtain peat we can learn much about its nature. The surface is usually covered with heaths and mosses and the bog is gradually thickened by these plants sending out fibres upwards and decaying in their lower parts, 'the individual thus becoming' it has been said, 'in a manner immortal and supplying a perpetual fund of decomposing vegetable matter.' The accumulation that goes on is therefore similar to that which results in the formation of coral, for it has been shown that the coral-polyps grow upwards, whilst their

and, on the average, the amount for mines is 50 feet. The following table gives a comparison of the results obtained in three different deep bore-holes:—

Name and Location of Bore-holes.	Total Depth in Feet.	Temperature at Top.	Temperature at Bottom.	No of Feet for 1° F.
Sperenberg, near Berlin	4,170	47·8°	118·6°	59·2°
Wheeling, Vancouver	4,500	51·3°	110·3°	74·0°
Schladabach, near Leipsic	5,740	51·9°	135·5°	65·0°

The rise of temperature is not constant with increase of depth.—This will be seen from the above table. Thus, at Wheeling bore-hole, which, by the way, is a little more than 4 inches in diameter, the increase was about 1° F. for 80 to 90 feet of descent down to about 2,000 feet, but after this a more rapid increase, about 1° F. for 60 feet, was found. This is due to some extent to the difference of conductivity and specific heat of the rocks passed through. Taking all observations into consideration, it seems that an average rise of 1° F. for 50 feet of descent is fairly near the truth. In Hungary and North Italy the abnormal rate of 1° F. for 20 feet has been found, but this is accounted for by the fact that these places have been the seat of volcanic action in comparatively recent times. At Yakoutzk, in Siberia, a boring was made through 620 feet of frozen soil, and a uniform rise of temperature of 1° F. for every 52 feet was found.

Other Evidences of Internal Heat are afforded by the existence of volcanoes from which steam, and other heated vapours, and streams of molten rock are ejected from time to time; and also by hot springs such as that at Bath, which issues from the earth at a temperature of about 120°. Some of the metamorphic rocks also testify to a high internal temperature. It must be borne in mind, however, that we have no direct evidence of the temperature of rocks other than those near the surface, and can only estimate what the temperature of the interior would be if the average rate of increase were 1° F. for every 50 feet of descent.

The Temperature at the Earth's Interior.—If the temperature is supposed to increase uniformly 1° F. for every 50 feet of descent, we get an increase of about 105° F. for every mile. At this rate the temperature would be sufficient to melt all the known rocks at a depth of 20 or 30 miles, and at a depth of from 200 to 400 miles, that is, about one-tenth of the earth's

radius, the temperature would be as high as that of the surface of the sun. It appears probable from this that the rate of increase is not uniform, and there are mathematical reasons for believing that below a depth of about 5,000 feet it is *nil*. Although the temperature at a particular depth may be sufficient to fuse rock, this does not prove that the rock is really in a molten state. The melting point of a solid increases when the pressure upon it is increased. Thus, rocks in any part of the earth beneath the surface may be at a far higher temperature than that at which they would melt, under ordinary circumstances, at the surface, and may yet remain solid on account of the enormous pressure exerted upon them by overlying strata.

A volcano, according to popular ideas, is 'a burning mountain, from the summit of which issue smoke and flames.' That this is entirely erroneous has been proved by investigators who have taken the trouble to investigate the phenomena in a scientific manner. Professor J. W. Judd in his work on 'Volcanoes,' remarks how utterly misleading such a statement is, in the following words, 'In the first place the action which takes place at volcanoes is not "burning" or combustion, and bears, indeed, no relation whatever to that well-known process. Nor are volcanoes necessarily "mountains" at all; essentially, they are just the reverse—namely, holes in the earth's crust or outer portion, by means of which a communication is kept up between the surface and the interior of our globe. When mountains do exist at centres of volcanic activity they are simply the heaps of materials thrown out of these holes, and must therefore be regarded not as the cause, but as the consequence of the volcanic action. Neither does this action always take place at the "summits" of volcanic mountains, when such exist, for eruptions occur quite as frequently on their sides, or at their base. That, too, which popular fancy regards as "smoke" is really condensing steam or watery vapour, and the supposed raging "flames" are nothing more than the glowing light of a mass of molten material reflected from these vapour clouds.'

A definition of a volcano which would include all the different classes on our globe is not easy to find, and is perhaps unnecessary if the foregoing paragraph is well understood. Sir Archibald Geikie says, 'The word "volcano" is applied to a conical hill or mountain (composed mainly or wholly of erupted materials), from the summit and often also from the sides of which hot vapours issue, and ashes and streams of molten rock

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It is therefore interesting to trace back the origin of this constituent. Plants of the carboniferous age furnished the carbon, but where did they get it? The answer is, from the carbon dioxide existing in the atmosphere at the time of their growth. Plants have the power of absorbing gases from the air. Under the influence of light the green colouring matter, called chlorophyll, of a plant is able to absorb carbon dioxide, to liberate the oxygen contained in it, and assimilate the carbon into its own tissues. We see, therefore, that the part of the solar energy received by the earth during the carboniferous period caused plants to absorb carbon. The plants were eventually buried in the manner previously described, and we now use the resulting formation for fuel. This being so, the heat produced by the combustion of coal, and utilised in the driving of steam engines and numerous other ways, is energy of which the first source was the sun. George Stephenson was therefore perfectly correct when he said his locomotives were driven by 'bottled sunshine.'

QUESTIONS ON CHAPTER XI.

1. Into what simple compounds can a piece of pure limestone be separated, and by what means? (1887.)
2. Of what chemical elements are plants chiefly composed? and how does coal differ in composition from the plants from which it was formed? (1886.)
3. In what way is carbonate of lime separated from a state of solution in waters to form the substance of limestone rocks? (1886.)
4. State what you know concerning the difference in chemical composition between peat and coal. (1885.)
5. Give the names of the chemical elements which make up the greater portion of plants and animals. What compound bodies are most commonly given off during the decay of animal and vegetable substances? (1884.)
6. What materials are taken from the atmosphere by plants, and what becomes of these materials? (1883.)
7. Describe the chemical constitution and microscopic structure of a piece of chalk. (1882.) Explain the formation of coal. (1881.)
8. Give a short account of the organism by which coral-reefs are formed. (1882.)
9. Where are reef-building corals found, and under what conditions do they flourish?
10. What is the chemical composition of a piece of common coal, and how does it differ in composition from peat on the one hand, and anthracite on the other? (1879.)
11. Why are coral-reefs limited to certain restricted areas of the earth's surface? (1877.)

CHAPTER XII.

VOLCANOES, EARTHQUAKES, AND OTHER PHENOMENA DUE TO THE ACTION OF FORCES IN THE INTERIOR OF THE EARTH.

The Density of the Earth increases from the surface to the interior.—The average density of the rocks which constitute the earth's crust is about 2·5. The mean density of the globe as a whole is about 5·6. From this we see that the interior of the earth must be made up of materials heavier than those which form the crust. There is little doubt that the earth consists of strata which gradually increase in density from the crust to the centre, so that at any great depth the density of the layers is approximately the same. The concentric shell at a depth of about 2,000 miles has a density equal to that of the globe as a whole, viz., 5·6. Above this depth the rocks are specifically lighter, below it they are specifically heavier, and it has been estimated that the density at the centre is about 9 or 10.

The Temperature of the Earth increases in passing down from the surface.—There are reasons for believing that at one time the earth must have been a globe of vapour as hot or even hotter than the sun is now. As it cooled down it gradually assumed the solid condition in which it is at present. But that it still retains some of this primitive heat is proved by observations of the temperature of the interior. There are two ways in which the rise of temperature may be determined, viz.: (1) by carrying thermometers down mines or tunnels and noticing the temperature at different depths, and (2) by letting maximum thermometers down deep wells, or making deep borings with rods having maximum thermometers attached to them. The latter method gives the best results, because in mines there are men, horses, firing of gunpowder, and various other causes which tend to make the observations somewhat inaccurate. By such observations as these it is possible to determine the number of feet of descent which produces a change of temperature of 1° F.,

and, on the average, the amount for mines is 50 feet. The following table gives a comparison of the results obtained in three different deep bore-holes:—

Name and Location of Bore-holes.	Total Depth in Feet.	Temperature at Top.	Temperature at Bottom.	No of Feet for 1° F.
Sperenberg, near Berlin	4,170	47·8°	118·6°	59·2°
Wheeling, Vancouver	4,500	51·3°	110·3°	74·0°
Schladabach, near Leipsic	5,740	51·9°	135·5°	65·0°

The rise of temperature is not constant with increase of depth.—This will be seen from the above table. Thus, at Wheeling bore-hole, which, by the way, is a little more than 4 inches in diameter, the increase was about 1° F. for 80 to 90 feet of descent down to about 2,000 feet, but after this a more rapid increase, about 1° F. for 60 feet, was found. This is due to some extent to the difference of conductivity and specific heat of the rocks passed through. Taking all observations into consideration, it seems that an average rise of 1° F. for 50 feet of descent is fairly near the truth. In Hungary and North Italy the abnormal rate of 1° F. for 20 feet has been found, but this is accounted for by the fact that these places have been the seat of volcanic action in comparatively recent times. At Yakoutzk, in Siberia, a boring was made through 620 feet of frozen soil, and a uniform rise of temperature of 1° F. for every 52 feet was found.

Other Evidences of Internal Heat are afforded by the existence of volcanoes from which steam, and other heated vapours, and streams of molten rock are ejected from time to time; and also by hot springs such as that at Bath, which issues from the earth at a temperature of about 120°. Some of the metamorphic rocks also testify to a high internal temperature. It must be borne in mind, however, that we have no direct evidence of the temperature of rocks other than those near the surface, and can only estimate what the temperature of the interior would be if the average rate of increase were 1° F. for every 50 feet of descent.

The Temperature at the Earth's Interior.—If the temperature is supposed to increase uniformly 1° F. for every 50 feet of descent, we get an increase of about 105° F. for every mile. At this rate the temperature would be sufficient to melt all the known rocks at a depth of 20 or 30 miles, and at a depth of from 200 to 400 miles, that is, about one-tenth of the earth's

radius, the temperature would be as high as that of the surface of the sun. It appears probable from this that the rate of increase is not uniform, and there are mathematical reasons for believing that below a depth of about 5,000 feet it is *nil.* Although the temperature at a particular depth may be sufficient to fuse rock, this does not prove that the rock is really in a molten state. The melting point of a solid increases when the pressure upon it is increased. Thus, rocks in any part of the earth beneath the surface may be at a far higher temperature than that at which they would melt, under ordinary circumstances, at the surface, and may yet remain solid on account of the enormous pressure exerted upon them by overlying strata.

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A definition of a volcano which would include all the different classes on our globe is not easy to find, and is perhaps unnecessary if the foregoing paragraph is well understood. Sir Archibald Geikie says, 'The word "volcano" is applied to a conical hill or mountain (composed mainly or wholly of erupted materials), from the summit and often also from the sides of which hot vapours issue, and ashes and streams of molten rock

are intermittently expelled. The term "volcanic" designates all the phenomena essentially connected with one of these channels of communication between the surface and the heated interior of the globe.' The renowned American geologist, Prof. James D. Dana, defines the formation as follows :—

'A volcano is a mountain or hill, more or less conical in shape, which has a nearly central cavity at the top called a *crater*, and which discharges at times melted rock called *lava*, and also vapours or gases. The lava either *flows* down this or that side of the mountain in streams, or is projected into the air to fall around the vent or lava-source in fragments. The cooled fragments from a *projectile* discharge are called volcanic *cinders*, but the finer part, often, volcanic *ashes;* if not cooled on the descent, they are *drops* or *driblets*.'

It appears, therefore, that the essential feature of a volcano is an opening of some kind in the crust of the earth for the transport of heated material from the interior to the surface. This opening is usually in the form of a crack or fissure, and the more or less circular crater which characterises most of our modern volcanoes only represents one of a series of vents along it. We shall refer to this point again.

The word Volcano or Vulcano was the name given by the ancients to a 'burning mountain' in the Lipari Islands, which was thought to be the forge or workshop of Vulcan, the Roman God of Fire, and from the name of this little island in the Mediterranean the word volcano is derived.

Volcanic Action may be constant or periodic.—Stromboli, an island rising about 3,100 feet above the level of the Mediterranean, is an example of a European volcano permanently in action. Records exist showing that since about 400 B.C. it has been emitting vapours and gases and ejecting masses of heated rock. There are other volcanoes in which the action is practically unceasing; this constancy, however, is exceptional. As a rule, volcanic action is intermittent. Continuous eruptions, like those of Stromboli, are rarely very violent, and the phenomena producing them can therefore be studied with little danger.

The volcanic phenomena exhibited by Stromboli were fully studied by Prof. Judd in 1874. One of the outbursts constantly occurring was described as follows: 'Suddenly, and without the slightest warning, a sound was heard like that produced when a locomotive blows off its steam at a railway station; a great column of watery vapour was at the same time

thrown violently into the atmosphere, and with it there were hurled upwards a number of dark fragments, which rose to a height of 400 or 500 feet above the crater, describing curves in their course, and then falling back upon the mountain. Most of these fragments tumbled into the crater with a loud, rattling noise, but some of them fell outside the crater, and a few rolled down the steep slope of the Sciarra into the sea. Some of these falling fragments were found to be still hot and glowing, and in a semi-molten condition, so that they readily received the impression of a coin thrust into them.' Further observations showed the existence of a red-hot seething liquid mass at the bottom of the crater, which illuminates the clouds of vapour sent out from time to time, and thus produces the appearance of flame, just as the smoke of a locomotive is caused to glow and apparently become self-luminous when the fireman opens the furnace door at night.

The phenomena displayed by Stromboli may appear to differ from the violent eruptions of such a volcano as Vesuvius, but really the difference is only one of intensity. The latter volcano, after an eruption, subsides to a stage of feeble activity of precisely the same character as that of the former one. In fact, the outbursts at Stromboli represent in miniature the more awe-inspiring and destructive eruptions, however great their intensity may be.

The materials ejected from a volcano during an eruption are of the most varied character. They may be classified into (1) Vapours and gases; (2) Molten rock which flows out in streams; (3) Fragments of rock ejected into the air. These will now be described in order.

Vapours and gases.—The vapour of water is always present and forms almost the whole of the white cloud which hangs over a volcano in action. Other gaseous products evolved are hydrochloric acid (HCl), sulphuretted hydrogen (H_2S), sulphur dioxide (SO_2), carbon dioxide (CO_2), Hydrogen, and Nitrogen. By the mutual action of sulphuretted hydrogen and sulphur dioxide on each other, free sulphur is produced. This accounts for the sulphur which so commonly occurs in volcanic districts. Other secondary products are similarly formed. Hydrogen and sulphuretted hydrogen are inflammable and burst into flame when they issue from the vents in the volcano. The flames are often coloured by incandescent sodium (derived from the common salt), copper, or other metallic

bodies. The amount of burning that goes on, however, is very small indeed and forms quite a subordinate part of an eruption.

Lavas are the molten, flowing products of volcanic action.—Lava may be discharged from the summit of a volcano or may flow out of cracks or other orifices at the side or base of the cone. Sometimes it never reaches the surface, but fills up cavities or forces its way between layers of rock and cools there, forming 'dykes' or walls of rock. Some lavas have the same general appearance as the clinkers and slags formed in furnaces.

As the molten material rises in the vent of a volcano, masses of rock are often broken from its sides and brought to the surface, so that in some cases the stream which overflows contains more rock of this character than ordinary volcanic matter. Many lavas contain material of the same kind as that which forms meteorites. This similarity is so great that some masses of an alloy of iron and nickel found in Greenland were for a long time said to be meteorites, but are now known to have had a terrestrial origin. Large crystals imbedded in a stony mass are commonly found in lavas, and these again indicate a place of formation deep in the earth's interior. Some lavas are entirely crystalline, and others have a vitreous or glassy structure, and exhibit very little, if any, crystalline arrangement. There is, in fact, every gradation from glassy lavas to those having the wholly crystalline structure of granite.

Scoriæ, or cinders, is the term used to denote the rough angular material, having the appearance of slag, ejected from volcanic vents. The cindery character is due to the escape of steam from a mass of liquid rock containing large crystals. These cinders are thus not unconsumed coal, like those of our fires, for no combustion goes on in a volcano. They are lumps of melted rock puffed high into the air by the explosion of steam in the lava as it rises in the vent of the volcano.

Pumice is formed from very fluid acid lava by the escape of the gases contained in the latter. That this is the case may be proved by holding a small piece of volcanic glass in a pair of platinum forceps, and heating it in a Bunsen burner. The glass becomes greatly distended by the expansion of the gases—chiefly water gas—it encloses, and a material differing in no respect from ordinary pumice is obtained. In like manner the water vapour *is generally* present in a great quantity in escaping lava, so that *directly the* stream reaches the surface, and the pressure is

therefore lessened, it suddenly expands and escapes, and by so doing transforms the lava into pumice. This material is too well known to need any description. It floats upon water because of its coarse porosity. When the air is removed from the numerous cavities the pumice sinks, for it is really heavier, bulk for bulk, than water. This is easily proved by powdering a lump of pumice and noticing how quickly it sinks in water. When this material is ejected from a volcano and falls upon the surface of water it floats for a long time, but eventually the thin partitions separating the air chambers from one another are broken down. The cavities then get filled with water, and the mass sinks.

Lapilli is the term given to ejected fragments of lava similar to scoriæ, but smaller—the size varying from that of a pea to a common marble.

Volcanic dust or ash is formed when the explosions are very violent and the lava very liquid. It is an extremely fine dusty powder, mainly produced by the scraping together of larger fragments. Masses of molten rock are also thrown out in such a strained condition that they are blown to powder when they reach the atmosphere. The ash is thus in no way connected with that which remains after the combustion of coal.

Volcanic bombs are masses of viscid lava which have been violently ejected from the column ascending in the pipe into the air. They whirl round in the air, and consequently are formed into more or less ellipsoidal masses, varying in size from a few inches to several feet. Owing to rapid cooling, the surface is sometimes glassy, though the escaping gas usually produces a cellular appearance in the inside of bombs, and often cracks the outside glassy covering.

Pelé's Hair is the name given to clots of lava having fine filaments or tails. In Hawaii, one of the Sandwich Islands, lakes of lava occur, within enormous craters, in a viscous condition. During the splashing out of steam from such craters, clots of lava are shot out into the air, and carry up long filaments or hairs from the surface. These often form thick deposits on the surrounding land surface, and have been named Pelé's Hair by the natives of Hawaii, Pelé being the name of a local goddess. The glass drops contain minute bubbles of gas, which often expand as the glass is drawn out. A similar material is produced artificially by blowing steam through the fused glassy slags of iron furnaces.

Volcanic Action may be Explosive or Effusive.—When the molten rock is highly charged with vapours and gases the explosive action is great, and the subterranean lava is ejected into the air in a fragmentary form. The eruption of Krakatoa, in 1883, when matter was shot up into the atmosphere six times higher than the summit of Mount Everest, was of the explosive class. So also was that of Mount of Tarawera, in New Zealand, in 1886, and that of Little Bandai-san, in Japan, in 1888, when the mountain of this name, standing 5,000 feet high, was suddenly blown into atoms. Java and Sumatra are also the seat of explosive volcanic action. When the explosive action is small the lava may flow out in streams. In Hawaii the lava is feebly impregnated with gases, and the action is therefore effusive. The great crater of Kilauea, in this region, has an area of nine square miles, and in it bubbles a surging mass of molten rock several hundred feet deep. The lava flows over the edge of the crater every few years, and this adds to the enormous mass of the mountain.

The transport of volcanic products occurs in different ways. Masses of pumice that have fallen on water surfaces may be carried hundreds of miles before they become water-logged and sink to the bottom. In fact, observations show that the ocean bottom is covered with a material which has been formed by the disintegration of pumice, and volcanic dust. The latter material is in such a finely-divided condition that it may be ejected by the escaping steam to a height of several miles above the surface of the earth, and be carried away to other regions by the upper currents in the atmosphere.

Lava streams are streams of molten rock that flow over the edge of a crater or issue from the sides of the cone. They soon cool at the surface, and present the appearance of moving streams of clinkers. The rate of movement of a lava-stream partly depends upon the degree of fluidity of the molten rock. Some sweep over a country and flood it like a river. Others, of a more viscous nature, creep along so slowly that careful observations are required to detect the movement. These often congeal before they reach the base of the volcanic cone. Acid lavas are less fusible than basic lavas, and also, as a rule, less liquid. The lava poured out from a volcano may have its degree of fluidity altered considerably during an eruption. It may issue at first in a very liquid state and flow smoothly for several miles from the vent, and then change to a viscid stream having no

flowing surface, and sometimes revert again to the liquid condition. Or the two kinds of streams may be emitted from the same volcano, at the same time, from different vents. The surface of the masses of lava in a slowly moving stream are covered with lines, which show that it cooled as it flowed from the volcano, and gave off little steam. This class of lava streams has a ropy, twisted, irregularly wrinkled appearance. Rapidly moving lava streams have surfaces consisting of jagged masses varying from an inch to a dozen feet in diameter, and difficult to walk upon on account of the numerous sharp points and angles. They give off enormous quantities of steam as they rush down the side of the volcano, and this swells the cloud of vapour that issues from the central vent. The rough surface of these lavas is partly due to the escape of steam. Indeed, small *parasitical* cones or miniature volcanoes are often formed on the surface of lava streams of this character by the escaping steam jets. The rate of flow of a lava stream is also dependent upon the inclination and form of the ground, and upon the volume of molten rock, as well as upon its fluidity. A stream was erupted from Vesuvius in 1805, which travelled nearly four miles in the first four minutes. The size of a stream may be enormous. In 1783 two streams of lava issued from Skaptar Jökull, in Iceland, one of which was 50 miles long and 15 miles wide, and the other 40 miles long by 7 miles wide, the average thickness of each being about 100 feet. It has been estimated that the quantity of matter which then escaped as lava would form a mountain equal in size to Mont Blanc. But currents of the acid type of lavas, such as obsidian, cease to flow at a very short distance from the vent, even when the slope of the ground is considerable.

The cooling of lava streams is very slow, and, in the case of a stream of any great thickness, may extend over hundreds of years. The outer crust of a lava soon cools sufficiently to permit it to be walked upon, whilst at the depth of a few inches the rock is red-hot. This is explained by the fact that the crust is an exceedingly bad conductor of heat, as are also scoriæ and volcanic dust. It is said that 'during the eruption of Vesuvius in 1872 masses of snow which were covered with a thick layer of scoriæ, and afterwards by a stream of lava, were found three years afterwards consolidated into ice, but not melted.' And, as a remarkable example of the retention of heat, an observer relates that 21 years after lava had been sent out from Jorullo, in Mexico, a cigar could be lighted at the cracks in the stream.

Volcanic cones are built up of materials that issue from an opening in the earth's crust. Much of the scoriæ and ash ejected into the air falls on the ground and forms a deposit which decreases in thickness with increased distance from the vent, so that a heap gradually rises, having the shape more or less of a truncated cone. With these fragments occur layers of lava which have flowed out of the top or sides of the volcano. The lava often fills up the cracks or fissures, which radiate from the central orifice through the cone, and form 'dykes,' sheets, or walls of igneous rock, which bind the cindery mass together. Volcanic cones vary in height from a few feet to several miles, according to the amount of material ejected. Some consist entirely of lava, others wholly of scoriæ and ashes, but in most cases they are built up of alternating sheets of these materials, spreading over each other in an irregular fashion, and forming what are known as 'composite cones.'

The forms of volcanic cones depend upon the kind of material ejected. Very liquid lavas produce flat cones, whilst with very viscid or stiff lavas the slope is considerable. In Hawaii, the western border of North America, and other places, basaltic lava flows out so copiously and freely as to flood the surrounding country, and cover it with layers having a scarcely perceptible slope from the vent. On the other hand, the lava sent out from many volcanoes in Hungary and the Island of Bourbon is of a pasty, consistent nature. It therefore accumulates round the crater, and forms steep, dome-shaped cones. In the district of Auvergne, in France, a number of dome-shaped hills occur, which were formed by the welling-up of a thick and viscous lava from volcanoes now extinct. (Fig. 109.) This district also contains a number of 'cinder-cones,' that is, cones composed almost entirely of scoriæ and other fragmentary products of an eruption. The amount of slope of the sides of cones of this character varies with the degree of fineness of the ejected material. Coarse materials may stand on a slope as much as 40° from the horizontal, whilst fine sand or ashes form much flatter structures. The structure of a cinder cone is diagrammatically shown in Fig. 110.

In cases where the lava in a volcanic vent is not crystalline but glassy, pumice is ejected instead of scoriæ, and white 'pumice cones' are formed instead of black cinder cones. The angle of slope is about the same for both these materials. Cones composed entirely of pumice are found in the Lipari Islands. On account of the condensation of the water-vapour sent out during

Fig. 109. Extinct Volcanoes in the Puy-de-Dôme Chain, Auvergne.

Fig. 110. Diagrammatic section of a Cinder Cone.

an eruption, rain often descends in torrents. This mixes with the ashes and other fragmentary products, and forms a flowing mud which consolidates into a material termed 'tuff' or 'tufa.' The streams thus produced build up 'tuff-cones,' having an angle of about 15° or 20°.

The formation of volcanic mountains is thus simply due to the accumulation of material derived from the interior of the earth. This is strikingly proved by the existence, near Vesuvius, of a little mountain called Monte Nuovo, or the New Mountain, whose creation was actually witnessed. The mountain is composed of scoriæ, lapilli, and volcanic dust. It is 440 feet high, and more than a mile and a half wide at the base, and there is indisputable evidence that it was built up in a couple of days in September, 1538. According to various observers a fissure first opened, within which molten rock was visible. From this, in the words of a witness, 'Stones and ashes were thrown up, with a noise like the discharge of great artillery, in quantities which seemed as if they would cover the whole earth; and in four days their fall had formed a mountain in the valley between Monte Barbara and Lake Averno of not less than three miles in circumference, and almost as high as Monte Barbara itself.' Another witness says, 'Some of the stones were larger than an ox. The mud was at first very liquid, then less so, and in such quantities that, with the help of the above-mentioned stones, a mountain was raised 1,000 paces in height.' There is little doubt that all volcanoes are built up in a similar manner, although they may not have been 'caught in the act,' as in this case. Eruptions take place below sea-level, and the material thrown out sometimes accumulates until a volcanic cone or island is formed above the water surface. Such eruptions usually occur where the water is comparatively shallow, for at great depths the pressure of the overlying water would be so enormous as to prevent the outburst. In 1831 a scoriæ-cone, called Graham's Island, was thrown up off the coast of Sicily by an outburst of a submarine volcano, but it was soon washed away by the sea. In October of 1891 a submarine eruption occurred about three miles to the west-north-west of Pantellaria. The sea was first seen in violent commotion, and a strip about half a mile long was gradually formed by the floating volcanic material. The interior of some of these masses was found to be hot enough to melt zinc, a week after they had been ejected. This formation disappeared in a few days as the brittle cindery bombs became water-logged and sank.

The agency of water in volcanic eruptions cannot be comprehended before some circumstances affecting the temperature of the boiling-point are understood. At sea-level and under an atmospheric pressure of 30 inches of mercury (equivalent to 15 lbs. per square inch), water boils when it reaches a temperature of 212° Fahrenheit. We have shown (page 91) that water, or any other liquid, boils when the tension or pressure of its vapour is equal to the pressure upon its surface. Hence we may say that the pressure or tension of water vapour at 212° Fahrenheit is equal to that of the atmosphere under ordinary circumstances. If the pressure on the surface be increased, water requires to reach a higher temperature before it boils. Thus, under a pressure of 24 atmospheres (360 lbs. per square inch), water remains liquid until its temperature is raised to 432° Fahrenheit, and for a pressure of 300 atmospheres it is not converted into vapour before a temperature of about 750° Fahrenheit is reached. We see, therefore, that water may be kept in a liquid state at great depths (although at a very high temperature) by the overlying strata exerting upon it an enormous pressure. If the pressure is lessened from any cause, the imprisoned water immediately bursts into steam, and in so doing may send out portions of the overlying rock with great force.

A Theory of Volcanic Action founded upon observation and supported by the foregoing facts was formulated by Scrope, and is now generally accepted. The rise of lava in the pipe of a volcano may thus be caused 'by the expansion of volumes of high pressure steam generated in the interior of a mass of liquefied and heated mineral matter within or beneath the eruptive orifice,' so that the vapour reaches the air 'in a state of extreme condensation and entangled in the liquid lava, which rises with it and escapes outwardly just as any other thick or viscid matter exposed to heat from beneath in a narrow mouthed vessel boils up and over the lip of that aperture.' Following Scrope, Professor Judd considers that volcanic outbursts are 'due to the accumulation of steam at volcanic centres, and that the tension of this imprisoned gas eventually overcomes the repressing forces.' And again, 'In the expansive force of great masses of imprisoned vapour we have a competent cause for the production of the fissures through which volcanic outbursts take place.' Briefly then the cause of explosive volcanic action is the expansion and escape of masses of high pressure water-vapour. On this theory water plays a primary part in volcanic eruptions. It has been

asserted, however, that the agency of water is only secondary, and that the flow of lava is really caused by the cooling and contraction of a solid crust upon a hot and yielding interior.

The grounds on which it is inferred that volcanic eruptions take place through fissures in the earth's crust are based on various facts. An opening of some kind is necessary for the vapours, lavas, and fragmentary materials to reach the surface. The first effect of an explosion of steam in the interior of the earth would be to form a crack or fissure in the earth's crust, just as cracks are produced in the sides of a boiler by the sudden production of water-vapour. Some portions of the fissures get choked up, whilst others, by their greater width or better situation, offer facilities for the escape of the heated rock. One or more vents are thus established along the line of fissure, and volcanic cones built up around them. Evidence of the existence of such fissures is also afforded by the fact that volcanic eruptions take place successively along certain definite lines. This linear arrangement is strikingly illustrated in the Lipari Islands, where three fissures appear to have been produced, along which eruptions have taken place, and volcanic cones thrown up at various points. An even more convincing proof is that fissures have been seen to form at Vesuvius and Etna during eruptions. On the side of Etna in 1865 and 1874 a number of distinct scoriæ-cones were produced above fissures in which molten rock could be seen.

The number of Volcanoes that in recent times have been in a state of activity is rather more than 300. If the 'mountains,' which from their conical form, craters, &c., are believed to be extinct volcanoes, are included, the total is not far short of 1600. And by counting mountains consisting of volcanic matter, but without the conical form, the list is further increased. Geysers and constant hot springs, fumaroles, and mud volcanoes, are also volcanic phenomena, and these are very numerous.

The linear distribution of volcanoes on the earth is well exhibited by Fig. 111. Most of the active volcanoes on the globe are situated on islands, on the edges of continents and near the sea. Thus, about 200 active volcanoes occur on islands in the various oceans, and, with two exceptions, the remainder occur on continental coasts. There is a continuous chain of volcanoes running along the Andes of South America, Central America, and the Rocky Mountains past the Aleutian Islands down to *Japan, and* reaching a maximum of activity in Formosa, the

Philippine Islands, and the Malay Archipelago. At this point the line of volcanic activity divides into two branches; one turns north-westward through Java and Sumatra—regions of frequent

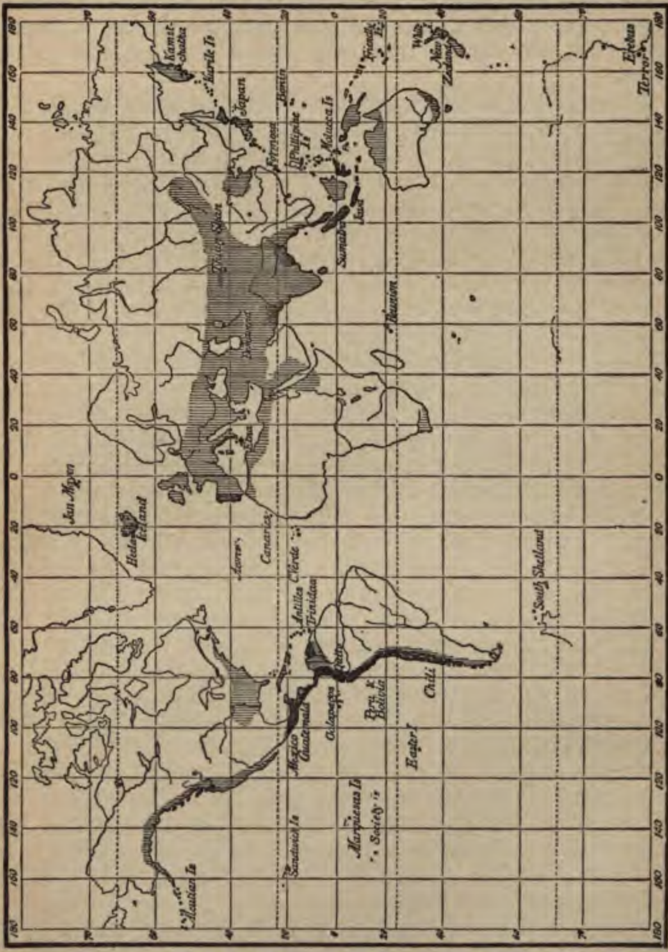

Fig. 111. Distribution of Volcanoes and Earthquakes. The former are indicated by dots, the latter by shading.

and great volcanic eruptions—along the eastern side of the Bay of Bengal; the other turns south-eastward through New Guinea and the New Hebrides into New Zealand, and across the Pacific to South America by the Friendly, Society, and Easter Islands. Thus the Pacific is encircled with a vast ring of active volcanoes. A similar, though not so distinct line, may also be traced around the Atlantic.

The fact that these lines follow very nearly the direction of great lines of elevated land is very important, for they probably represent lines of relief or fracture in the earth's crust produced by volcanic action. Even in those mountain-ranges where no active volcanoes occur, investigations sometimes show that they once existed but are now dormant.

Vesuvius is a volcano of which every schoolboy has heard, so some few facts from its history should be of interest. It is situated upon the shores of the Mediterranean, and is the only volcanic vent now in action on the mainland of Europe. In 63 A.D. a terrific earthquake occurred in this region, which nearly ruined the town of Pompeii. In 79 A.D. another eruption took place, and totally destroyed Pompeii, Herculaneum, and numerous villages. Of the products of this explosion, Dr. Johnston-Lavis has written 'The character of the ejectments can be beautifully studied in the streets of Pompeii, where they are separable into three divisions of (1) white vitreous pumice, 6 feet, (2) darker micro-crystalline pumice, 6 to 12 feet, (3) pumice dust, which is nearly always pisolitic and of variable thickness. At Herculaneum these several materials, mixed with others into one rather uniform paste, have gradually consolidated into a more or less compact yellow tuff, which attains a thickness of 60 feet or more, whilst that which covers Pompeii rarely exceeds 25 to 30 feet, and often is much less. At Pompeii the regular arrangement and stratification indicate that the materials fell through the air, whilst those at Herculaneum, on the other hand, owe their present arrangement to the action of water collecting and transporting the materials down some valley.'

Numerous other great outbursts have been recorded, and 'In 1631 there occurred one of the most terrible eruptions of Vesuvius. It was not of the explosive, but rather of the paroxysmal type, and besides the fragmentary ejecta, consisting of scoriæ, lapilli, sand, etc., numerous large streams of lava poured down the slopes of the volcano, burning up in their course and burying towns and villages with a great destruction of life. Since this date the volcano has never been completely dormant for any

length of time. Generally its activity consists of feeble but constantly varying explosions at the main vent, accompanied often by a slight dribbling of lava from some lateral opening near the summit of the great cone. This state is interrupted from time to time by paroxysmal eruptions which are due to the formation of radial dykes extending from the main chimney outwards to the

Fig. 112. Eruption of Vesuvius, in April, 1872. Based upon a photograph by Professor Palmieri.

slopes of the cone. As much of the lava as there is in the main chimney, above the level of the new vent, drains off immediately, thus lightening by so much the pressure on the remainder, which, consisting of a solution of a gas in a liquid, immediately on the pressure being reduced, froths up and issues forth after the first lava by the lateral outlet whilst most of the vapour escapes up the main chimney.'

But the eruption of which we possess the most complete account occurred in April, 1872. The appearance of the volcano at the time of greatest activity is shown in Fig. 112, which is based upon a photograph by Professor Palmieri. The advent of the outburst was heralded by earthquakes shaking the surrounding country. Wells dried up, springs disappeared, and subterranean noises were heard. Eventually fissures were formed on the flanks of the mountain, and out of some of these, and the crater at the top, enormous volumes of steam, carrying with them masses of rock, were hurled. Lava streamed from the sides and crater of the volcano, and from it escaped great volumes of steam to increase the bulk of that from the crater. The friction of the steam on the interior of the vent developed electricity which gave rise to lightning discharges with the accompanying thunder. The tall column of steam, resembling in form the Italian stone-pine, and a usual appendage to an eruption, was broken up by wind. The evolution of such a vast quantity of water-vapour caused the atmosphere soon to become saturated with moisture. Rain consequently fell in torrents, and, with the loose volcanic fragments, formed streams of mud, which quickly flooded whole districts.

During such an eruption as this remarkable changes may occur in the structure of the mountain. The ejected material swells the size of the cone, new craters are often formed inside the original one, and cones built up around them, and sometimes a terrific outburst will blow away the whole or part of a mountain. An example of this will be found in the following paragraph.

The eruption of Krakatoa which took place in August, 1883, is one of the most violent on record. Previous to this Krakatoa was a small, oval-shaped island in the Straits of Sunda, between Java and Sumatra. Slight disturbances began in May, and on August 26 & 27 one side of the cone was almost completely blown away by a series of terrific convulsions. A perfect section of a volcanic cone was thus obtained, from which a true idea of the internal structure of a volcano was learnt. The

fragmental products which formed the cone had a general slope away from the central vents. Dykes or walls formed by the solidification of molten rock in fissures, crossed the cone in all directions. Many of the fissures reached the surface at the sides of the cone and formed ducts from which lava flowed. Where the fissures were large, *lateral*, or *parasitical* cones were produced. The rock injected into the fissures beneath the surface only became visible after the layers of ash, scoriæ, and other volcanic products that they traversed had been washed or worn away. It has been estimated that about $1\frac{1}{8}$ cubic miles of rock was blown into atoms by this tremendous explosion, the effects of which were numerous and great. The dust was observed to fall more than 1000 miles distant. The ejected pumice almost filled the Sunda Straits, and was carried by winds and ocean currents to very distant regions. The disturbance in the atmosphere caused variations in the height of the barometer. Observations of these fluctuations show that a wave of compressed air started from the scene of the explosion, with a velocity of about 700 miles an hour, spread out until it encircled the globe, and then contracted to the antipodes of Krakatoa, where it formed a focus and was reflected back to the place of its origin. It again began its journey, was again reflected back, and its effects were observed in this manner four times from Krakatoa and three times back, after which it had spent its energy. The sound of the explosion was heard at all places within 2000 miles of Krakatoa, and even at a distance of 3000 miles. The sea disturbance was composed of two kinds of waves, long waves occurring at intervals of over an hour, and shorter but higher ones which rolled in at irregular and brief intervals. The greatest convulsion at Krakatoa produced a wave 50 feet high on the shores of the Strait of Sunda, and at some places it was said that the tide rose 100 feet higher than usual. But the velocity of the sea-waves and the height to which they rose depended upon the depth of water and form of the shores. Some of the dust from the volcano was sent up from 16 to 20 miles in the air, carried all over the globe by currents in the upper regions of the atmosphere, and took years to descend. In the winter of 1883, and the spring of the following year, remarkable and brilliant twilight glows were observed, the sun was often seen of a blue, or green or other unusual colour, and large coronæ appeared round it and the moon. There seems little doubt but that all these, and similar optical effects, were due to the presence in the atmosphere of fine volcanic dust.

Geysers are eruptive fountains of hot water and steam, and differ only from ordinary volcanoes in not bringing liquid rock to the surface. But they do bring up immense quantities of mineral matter (silica, carbonate of lime, &c.) dissolved in the water. The heated water becomes alkaline by dissolving soda and potash from rocks containing it, and this enables it to dissolve silica—the chief substance brought to the surface. The silica is deposited as *sinter*, as soon as the water that contained it

Fig. 113. Sinter Terraces in Yellowstone Park (U.S.A.).

has cooled and evaporated sufficiently. It therefore accumulates mostly around the orifice and builds up a kind of tubular projection. In this connection, however, it should be remarked that the ninth annual report of the United States Geological Survey contains an array of facts which seems to prove that the sinter owes its origin, not to evaporation, but to the agency of *algæ living in* the heated waters. When a hot spring issues at

the top of a slope the deposit forms a succession of terraces having basins of more or less heated water in them (Fig. 113). Geysers occur very largely in Iceland, Yellowstone Park (U.S.A.), and New Zealand. There are more than 3,000 geysers in Yellowstone Park in the Rocky Mountains. One throws up jets 250 feet high every few weeks. Several others spout out jets about 200 feet high at intervals of about a day, and one, known as Old Faithful, has sent out a column of water and steam 150 feet high every hour since this region was discovered. Geysers are also found in Mexico, the West Indies, the Azores, and other places. When geyser action takes place through rocks of a clayey nature the water often forms a mud. The material thus brought up in suspension in the water builds up small cones. Such mud springs are known as *mud volcanoes*. In some localities hot vapours and gases escape from cracks in the ground. These eruptions are termed *solfataras*. Geysers, mud-volcanoes, and solfataras are manifestations of declining volcanic action. Many regions in which volcanic action was once rife are now perfectly free from it. In the Auvergne district of central France there are hundreds of cones, from which melted rock was at one time erupted, but which are now dormant, and evidences of former volcanic action are found in many parts of Great Britain.

Earthquakes are vibratory movements of the earth's crust.—The explosion of a torpedo deep down in the sea causes a series of undulations to be set up and a series of concentric waves to appear at the surface. Explosions in mines cause similar vibrations, which travel through the rocks of the earth and are felt at the surface. In like manner any disturbance in the interior of the earth—it may be due to the sinking of rocks, or the sudden generation of a mass of steam—sets the rocks in vibration as if they consisted of a jelly; a system of waves starts from the point where the shock occurred and spreads out in all directions. It is the passage of such waves that constitutes an earthquake or earth-tremor.

Some of the effects of a great earthquake on buildings were described by a writer in 'Nature,' in December, 1891, in connection with the lamentable catastrophe that happened in Japan in October of the same year. It is recorded that 'cotton mills have fallen in, whilst their tall brick chimneys have been whipped off at about half their height. Huge cast-iron columns, which, unlike chimneys, are uniform in section, acting as piers for railway bridges, have been cut in two near their base. In some

instances these have been snapped into pieces much as we might snap a carrot, and the fragments thrown down upon the shingle beaches of the rivers. The greatest efforts appear to have been exerted where masonry piers carrying 200-feet girders over lengths of 1,800 feet have been cut in two, and then danced and twisted over their solid foundations considerable distances from their true positions. These piers have a sectional area of 26 × 10 feet, and are from 30 to 50 feet in height. Embankments have been spread outwards or shot away, brick arches have fallen between their abutments, whilst the railway line itself has been bent into a series of snake-like folds and hummocked into waves. The greatest destruction has taken place in the Okazaki-Gifu plain, where we have all the phenomena—like the opening of crevasses, the spurting up of mud and water, the destruction of river banks, &c. —which usually accompany large earthquakes.'

Earthquakes are common phenomena, and it is on account of the great loss of life and property which accompanies violent shocks that their effects are often considerably exaggerated. It is probable that an hour never passes without some earth-tremor, due to subterranean changes, occurring. Minute movements of this character are detected by instruments called *seismometers*. Although a violent earthquake may produce great changes in the earth's crust they are as nothing compared with the grand movements which take place unnoticed.

The districts in which earthquakes occur most frequently are generally those in which volcanoes exist, but as will be seen from an inspection of Fig. 111, the two phenomena do not always accompany each other. The Andes of South America and a well-defined line passing through Further India and across Asia to Southern Europe are great centres of earthquake and volcanic action. In comparatively low-lying regions, such as the central parts of South America, Russia, and Australia, shocks are much less frequent.

Earthquakes produce three kinds of waves, viz., (1) Land waves, which travel with great velocity through the earth's crust; (2) Slower waves on the surface of the sea; (3) Waves in the air. The effect of the passage of the first kind of wave is to cause the ground to rise and fall, and sometimes open; whilst trees and houses are rocked to and fro and often thrown down. The rate of movement of this wave varies with the intensity of the shock. The movement of the land wave *causes* the bed of the ocean to vibrate, and is thus communicated

to the water, the result being that a large number of waves of water roll in upon the shore, as it were, on the back of the land wave. These produce no great effect. The next event which occurs in connection with an earthquake is the arrival of the sound-waves, to which the characteristic rumbling noises are due. The loud sounds that frequently accompany earthquakes may be propagated through rocks, water, or air. Three sounds may thus be received, the first one through the earth, then one conveyed by water, and the last and slowest through the air. The most destructive effect is due to a violent sea-wave, which often reaches the land several hours after the earthquake shock. It is produced by the sudden forcing up of the water into a heap directly over the place where the disturbance occurred.

The depth of an earthquake shock is found approximately by observing the direction of the cracks made in houses; this gives the angle at which the earth-wave reaches the surface (angle of emergence), and the position of the place where a vertical

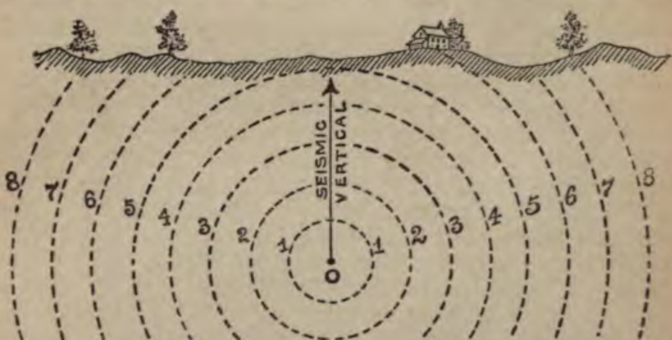

Fig. 114. Production of Earth Waves by a disturbance at O. The position of the Seismic Vertical and the direction in which waves strike the surface enables the depth of O to be calculated.

movement was experienced. This is directly over the centre of disturbance, and a line joining the two is called the *seismic vertical*. (Fig. 114.) With these data it is possible to make the required calculation.

From an investigation of the effects of an earthquake which took place at Calabria in 1857, Mallet found that the focus of

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place of occurrence was not a point but a plane five miles long and three miles broad, and having an average depth of nearly six miles below sea-level. The velocity at which the waves travelled varied in different rocks from about 650 to 1,000 feet per second. The amplitude of the wave, that is, the greatest length of the to-and-fro movement of the particles of rock, did not exceed three or four inches. It seems to be established that the depth of earthquake shocks very rarely exceeds thirty miles.

Slow movements of the level of the land occur, and are far more important than volcanoes and earthquakes in producing great changes in the form of the earth's crust. It is usual to speak of the sea as rising or falling with respect to the land, but the reverse is really the case. If a large volume of water could be added to an ocean the effect would be a rise of water level all over the world. And if a large amount could be taken away there would be a general lowering of the sea-level. But the volume of water in the oceans is practically constant, hence the height of the sea relatively to the land would remain constant if no movements of the land took place. In other words, the level of the sea may be regarded as a fixed standard by means of which we are able to determine changes of level of the land surface.

Evidence of elevation of land above sea-level is found in 'raised beaches.' A sea beach consists of gravel and sand, generally mixed with shells and other remains of organisms. Its limit on the land side is the high water mark, and the lower limit is reached by the margin of the sea at low tide. When a beach, exhibiting signs of having been formed at sea-level, is found above the reach of the waves it is known as a 'raised beach,' and from its existence we learn that the land of which it forms a part has been elevated above sea-level. When the land has been subjected to slow movements of upheaval, alternating with periods of rest, a series of raised terraces or beaches, each lower than the one previously formed. But where the land has been gradually rising for a very long time, unbroken by pauses, a gentle slope runs from the oldest and highest beach to that now existing, and there are no steps as in the former case. Numerous old sea-beaches containing marine shells are found on the west coast of South America. Near Valparaiso they reach a height of 1,300 feet and near Chili about 1,000 feet above the sea-level. Similar proofs of upheaval occur in the south of New Zealand, in Corsica, and Spitzbergen. In Scotland, also, we have good examples of these changes of level, many of the

towns and villages along the firths being built on raised beaches, of which there are five at heights of 25, 40, 50, 75, and 100 feet above the existing sea-level. Caves worn out of rock by the action

Fig. 115. Sea-worn Caves, raised above the present sea level, Fifeshire. (*From a Photograph by Wilson of Aberdeen.*)

of the waves often form part of a raised beach. (Fig. 115.) Their sea-worn appearance proves beyond doubt that they were once exposed to the full force of the waves, although now perhaps covered with vegetation. Sea-worn caves thus afford another proof *of upheaval.* Besides these indications we have historical

evidence of changes of level. Old seaports in Candia have been rendered useless by being raised above the water. In Finland the coast has been observed to have risen 76 inches in 127 years, this being at an average rate of about $1\frac{1}{2}$ inches a year. From marks made on the north coast of Sweden last century, a similar rise has been established.

Slow movements of subsidence, or sinking of the land below sea-level, are also continually going on in some parts of the earth. Very remarkable examples of this kind of change are met with in Scotland, Norway, and the west coast of Ireland. In these countries we find sea-lochs, or firths, or fiords, in which the sea runs up long, narrow, and deep channels or inlets generally supposed to have been excavated by river action. If this supposition is correct, each fiord is a submerged valley and affords evidence that the surface of the country has moved downwards. But the river-origin is disputed, many believing that fiords have been excavated by ancient glaciers of the north. The remains of ancient towns found beneath the water on the eastern shore of Greece, and of submerged forests near Devon and Cornwall, and in the estuary of the Thames, testify to a slow subsidence of portions of the land surface of our globe. Similar evidence is afforded by the fact that the bases of coral reefs sometimes extend deep down in the ocean, although the reef-building corals cannot exist at a greater depth than twenty fathoms, the explanation of the circumstance being, according to the late Charles Darwin, that the rock to which the coral is fixed once stood at a depth less than twenty fathoms, at which period the coral-builders fixed themselves to it. As the rock gradually subsided the building upward went on, and the coral reef was thus always kept at sea-level.

QUESTIONS ON CHAPTER XII.

1. How has it been found out that the deeper parts of the earth's crust are hotter than those near the surface? (1890.)
2. State the grounds on which it is inferred that volcanic eruptions take place through fissures in the earth's crust. (1889.)
3. What is a lava stream? Of what does it consist, and how does it behave? (1887.)
4. What is a volcanic dyke; what is it like, and how is it formed? (1886.)
5. How has it been proved that some parts of the land of the globe has *undergone elevation* in recent times? (1886.)
6. *In what way* has the temperature of the deep-seated rocks of the earth's *crust been determined?* (1885.)

7. Of what are volcanoes composed? Why have they usually a conical shape? How have their 'craters' been formed? (1884.)

8. Give a drawing showing the internal structure of a cinder or scoriæ-cone. (1883.)

9. What are volcanic bombs, and how are they formed? (1882.)

10. Describe a raised-beach, and state what inference you would draw from its existence. (1881.)

11. What are fiords, and how do you suppose them to have been formed? (1880.)

12. In what respects do a volcano and a geyser resemble each other, and in what respects do they differ? Name the principal districts on the globe in which geysers are found. (1878.)

13. What is a volcano? Name the active volcanoes of Europe, and state in what part of the same continent *extinct* volcanoes occur. (1877.)

CHAPTER XIII.

ARRANGEMENTS OF ROCKS AND THEIR REPRESENTATION BY MAPS.

The condition of the earth's interior is a matter of discussion. The conclusion arrived at by Sir William Thomson (now Lord Kelvin) with regard to the physical constitution of the earth was that 'It is not, as commonly supposed, all liquid within a solid crust of from 30 to 100 miles thick, but that it is on the whole more rigid certainly than a continuous solid globe of glass of the same diameter, and probably one of steel.' But many arguments can be advanced in favour of very different theories. The enormous pressure of overlying strata is said to be sufficient to account for the increase of density which is found in passing from the earth's surface towards the centre. It is more probable, however, that the chemical composition of the rocks in the interior differs from that of the earth's crust, and differs mainly in being made up of unoxidised instead of oxidised materials. The only way of studying the chemical composition of the interior of the earth is by the study of the interior of similar bodies which come in our way. Such bodies are found in the meteorites which fall upon the earth. No element has been found in them that does not occur in the earth. But although all the elements found in great abundance in the crust may be present, the proportions are strikingly different. A meteorite commonly consists of iron

and nickel, and similar unoxidised materials have been found which have a terrestrial origin, but their occurrence is rare. The comparative high density of the earth's interior may therefore be due to the existence of specifically heavier and different materials instead of more compressed forms of the same.

The Evolution of the Earth.—Many reasons have been given for believing that the interior of the earth is at a high temperature. There is little doubt that the sun, earth, and our moon at one time were all at the same temperature. The three bodies are illustrations of the ordinary law of cooling, and for the same reason that a hot cannon ball takes longer to cool than a small bullet having the same temperature, we find the temperature of that enormous mass, the sun, considerably higher than that of the earth, and the temperature of the earth higher than that of its smaller companion, the moon. When the earth was in an intensely heated condition there was no hard and fast distinction between its atmosphere and surface, and all the rocks existed in the condition of vapour. As radiation into space went on, a relatively cool envelope was formed around an incandescent mass. The constituents of the envelope and the mass it enclosed became gradually cooled down to the point at which they solidified or chemically united with one another. The water vapour was then condensed, and fell copiously upon the earth's surface carrying down with it numerous saline substances from the atmosphere, and most probably giving our seas the sodium chloride they contain. Finally, a solid crust of igneous rock covered the hot interior, and above it rested, as at present, an atmosphere composed of gases, such as oxygen and nitrogen, which require a much lower temperature than has yet been reached by the earth to reduce them to the liquid or the solid form. Before the crust had solidified, and while the earth was in a soft or viscous condition, the rotatory motion caused the mass to bulge out at the equator and become flattened at the poles; to assume, in fact, the form of an oblate spheroid, which it now possesses. This mode of formation can be imitated by placing a quantity of oil in a transparent liquid of the same density. The oil floats in the liquid in the form of a globe as long as it is at rest, but when it is caused to rotate it becomes flattened at the poles, that is to say, at the extremities of the axis of rotation, and bulged out at the equator in a manner precisely similar to the earth. An apple gets wrinkled when kept for a time, the reason being *that the interior* which once filled out the skin has dried up again.

As people get old they lose the fat and muscle that once filled out their skin, and the latter becomes wrinkled. Both these cases show how a shrinkage of the interior causes a wrinkling of the crust; and the analogy may be applied to the earth to account for its ocean depressions and continental plateaus. But there are strong mathematical objections to this easily-understood mode of formation of the ocean basins, so too much credence must not be placed upon it.

Characters Impressed on Rocks during their formation.—The distinguishing characteristic of aqueous rocks is their stratification, an example of which is shown in Fig. 116. In almost all cases the strata were deposited horizontally. Currents, however, may cause the layers to be deposited on a gentle incline. In general the stratification is the more perfect when the materials deposited are finer, fine sand and mud often exhibiting a perfect form of stratification known as *lamination*, in which case the separate layers can be divided into thin leaves or *laminæ*. The materials of beaches may have *rill-marks* caused by the receding tide impressed upon them, and these are sometimes preserved. (Fig. 117.) The heat of the sun

Fig. 116. Stratified Rock.

Fig. 117. Slab of Stone, with ripple markings and footprints of an ancient newt-like animal, from the Carboniferous Limestone series of North America.

causes clays to crack, and the cracks often get filled with sand, and so a perfect cast of the crack is formed when the sand consolidates. Rain produces pittings on mud or soft sand, or

Fig. 118. Lion Rock, Millport. Example of an igneous dyke weathering more slowly than the sandstone through which it has been thrust. (*From a Photograph by Wilson of Aberdeen.*)

animals leave their foot-prints upon them, and these marks, *or casts of* them, are often preserved in shallow-water deposits. *Igneous rocks* are intruded among aqueous rocks, or ejected

at the surface. In the former case the intrusion takes place most easily between the deposited layers. Sometimes, however, the mass of igneous rock cuts through the strata almost vertically, and forms what is known as a 'dyke.' Such masses are not so easily worn away or weathered as the softer materials surrounding them, and so they often stand out like walls, as in Fig. 118. They differ from ejected lavas in having no scoriaceous upper and lower surfaces.

Changes which occur in rock-masses subsequent to their formation.—Loose sands, clay, shells, &c., are hardened into sandstones, slate, limestones, &c., by various processes, the process being termed *induration*. The material may be caused to cohere by mechanical pressure, but in the majority of cases it is the result of chemical action as well as pressure, the grains being cemented together by the deposition of substances from solution in the water which percolates through the loose material.

Changes which are the result of the action of external forces on rock masses.—Aqueous rocks in drying, and igneous rocks in cooling, contract, and this gives rise to jointing in them. If igneous rock masses did not break up in this manner it would be almost impossible to quarry them. Basalt in cooling sometimes develops a columnar structure, as exhibited in Fig. 119. In fact, a columnar or basaltic structure, more or less perfect, is very common in solidified lava. The production of the hexagonal form of the columns is due to the fact that contraction in a rock necessarily produces cracks, and as only three regular forms, the triangle, square, and hexagon, can completely fill a space, and the hexagon will do so with the least number of cracks, the tendency is for this form to be produced. Starch and mud often exhibit the same hexagonal cracks, and bees utilise the same principle of filling a space with the least amount of work, in the construction of the hexagonal cells of

Fig. 119.
Columnar structure assumed by basalt and other igneous rocks.

their honeycomb. Another way of looking at the matter is that the hexagon is a figure which has the greatest area for the least periphery which will fill a space. The circumference of a circle embraces a larger area than the circumference of a hexagon of the same length, but circles will not fill a space.

Cleavage is produced by pressure and is therefore a feature added to a rock by the action of external force. This has been referred to in describing the microscopic structure of slate (p. 185).

Curved strata.—In general, when strata are found in any position other than horizontal, it may be inferred that they have been disturbed since they were deposited. This is because the

Fig. 120. Curved Strata at Draughton Quarry. (*From a Photograph.*)

sediment of which the strata consists could only have been laid down horizontally or very nearly so. But it is the exception rather than the rule for strata to be found in this position. They occur curved and tilted up at all angles owing to the *crumpling of the* crust caused by the contraction of the earth;

and the angle contained between the plane of the strata and a horizontal plane is termed the 'angle of dip' or briefly 'dip.' When strata occur in wave-like crests and troughs, particular names are given to the curves, folds, or bends. The trough, shaped so ⌣, is known as a 'synclinal,' and the crest, shaped so ⌢, where the strata dip away from a highest point, is termed an 'anticlinal.' 'Trough' and 'saddle' are words often used instead of synclinal and anticlinal when the folds are very sharp and rapid. Two sharp synclinal and anticlinal folds in limestone are shown in Fig. 120.

Broken strata.—Movements of the earth's crust have bent some strata and broken others, and in some cases produced both effects. The fractures or displacements of strata formed in this way are termed 'faults,' an example of which is shown in Fig. 121. The effect of faulting, however, is rarely visible at the surface.

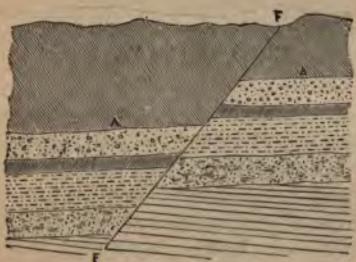

Fig. 121.

A Fault. The similarly shaded strata were once on the same level, but have been fractured since their deposition.

The parts of a stratum which appear at the surface are known as 'outcrops.' In other words an outcrop is simply one end of an inclined bed. A geological map shows the outcrops which occur in the districts surveyed. Thus in one place we have an outcrop of a bed of chalk, in another an outcrop of sandstone, and so on.

Unconformable strata.—When one set of strata has been tilted up into an inclined position, the upper edges of the beds are denuded away and a fresh series may be deposited upon the worn surface, having the same or a different dip. These newer deposits are then said to rest unconformably upon the lower ones, or the two sets of strata are said to be

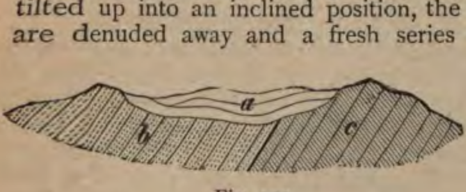

Fig. 122.

Unconformable strata. The beds *a* have been deposited after the beds *b* and *c* have been tilted up.

uncomformable. (Fig. 122.) For this to have happened, the older beds must first have been elevated, then denuded, then subsidence must have occurred and the newer beds were deposited; and, lastly, an elevation of the region must have taken place to bring the strata above the water surface. Whether the newer beds lie parallel to the older beds or not depends, of course, upon the manner in which the latter were upheaved and depressed.

An Escarpment is an inland cliff.—Escarpments are formed by the denudation of the edges of slightly inclined strata. Thus, in escarpments the surface of the country slopes gradually away from the denuded edge. (Fig. 123.) They are generally composed of a hard stratum lying upon softer ones.

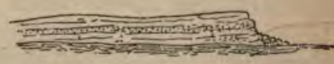

Fig. 123. An Escarpment.

Drawing to scale.—A photograph of a house, of a rock, or any large object, represents the original structure in miniature, and, if the lens of the camera is a good one, the breadth and height of the building or rock will be portrayed in their proper relative lengths, that is to say, if the object is twice as high as it is wide the photograph will show this. Let a photograph of a building 60 feet high by 30 feet wide exhibit the structure 6 inches high by 3 inches wide. Then, 60 feet is represented by 6 inches, and so 10 feet is represented by a length of 1 inch. But, 10 feet = 120 inches, so the photograph illustrates 120 inches by a length of 1 inch. In other words, dimensions on the photograph are 120 times smaller than those of the building itself. But it is not necessary to confine ourselves to photographs. The building could be measured, the measures could be divided by 120, and the results obtained could be used to make a drawing which, as far as size was concerned, would be like the photograph. In either case the picture would represent the object on a scale such that 1 inch = 10 feet or 120 inches. In constructing a map of England it is not of course convenient to use such a large scale as this, for a map $\frac{1}{120}$th the size of England would be a very large affair. Much smaller scales are therefore adopted. The Ordnance Survey Map of the United Kingdom is drawn on a scale of 1 inch to the mile, that is, the distances are $\frac{1}{63360}$ times less than those *originally* measured. Hence, a square inch on one of these maps *represents* a square mile, a length of 10 inches upon it is equal to

a distance of 10 miles, and so on for any other dimension. Maps of counties are constructed on a larger scale—6 inches to the mile—and others of towns and large parishes on a scale of 25 inches to one mile. Now, suppose it is required to draw to scale a pillar-box 4 feet high in a straight road a mile long. Four feet is $\frac{1}{1320}$th of a mile. If, therefore, we draw a line, say 6 inches long, to represent the mile, the height of the pillar-box would be $\frac{6}{1320}$ $= \frac{1}{220}$th of an inch. This amount is far too small to plot down, and the pillar-box would be undistinguishable on such a scale. When drawings have to be made in which horizontal distances differ so considerably from vertical ones, it is usual to adopt two scales, one for each set of measures. Thus, in the above case, the road could be drawn on a scale of 6 inches to the mile, and the pillar-box of 1 inch = 4 feet. The box would then be drawn having a height of 1 inch and the road would have a length of six inches. The picture obtained, when different scales are used in this manner, does not show the thing delineated in its true proportions, and beginners cannot be too careful in distinguishing between such *diagrammatic* illustrations and true ones.

Contour lines are lines passing through points at the same height above sea-level.—A bird's eye view of a district, if drawn or photographed, cannot represent heights in the manner described in the preceding paragraph. It is very

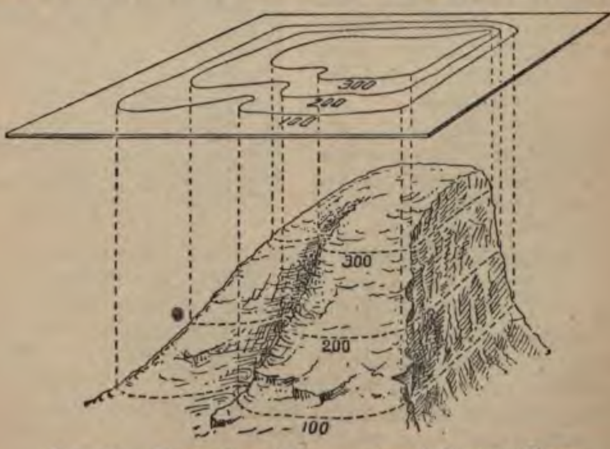

Fig. 124. Illustration of the meaning of Contour Lines.

necessary, however, that maps of small districts should show the character of the surface, with regard to mountains and other elevations, and this is done in two ways, viz., by *contour lines* and *hachures*. The average level of the sea is taken as the line of no elevation, and termed the *datum line*. If we now imagine the level of the sea to rise, say 100 feet, as indicated by a vertical rod or cliff, the water encroaches more or less on the land according as the beach has a more or less gentle slope; and a new contour line is formed 100 feet above the first. And if we suppose the sea to rise by steps of 100 feet until it covered the highest mountain peak, its margin would in each case mark out a contour line 100 feet above the preceding one. These suppositions can be experimentally illustrated by putting a rough block of stone in a vessel, and pouring water over it in amounts producing the same difference of vertical height. The form of the edge of water round the stone gives the form of the contour lines, and the difference between the altitudes of the lines is measured by the successive increase in height of the water measured vertically. The contour lines around a hill are illustrated by Fig. 124.

The method of indicating heights by *hachures* (Fig. 125) is used on the maps drawn on the scale of an inch to a mile. It consists in drawing shading lines thicker and closer together according as the ground increases in steepness. The summits of mountains are represented on this principle by the darkest shading, and the intensity gradually decreases down to the lowest ground.

Fig. 125. Hachures.

Diagrams of Vertical Geological Sections show the order, thickness, inclination, etc., of the strata in any particular district. The information from which they are constructed can be obtained to some extent by direct observation, but borings through the strata furnish the best information of the layers beneath the surface. A vertical section is shown in Fig. 126.

Diagrams of Horizontal Geological Sections represent *the positions* and form of the strata which would be seen if we *could make* deep vertical cuttings across the districts they

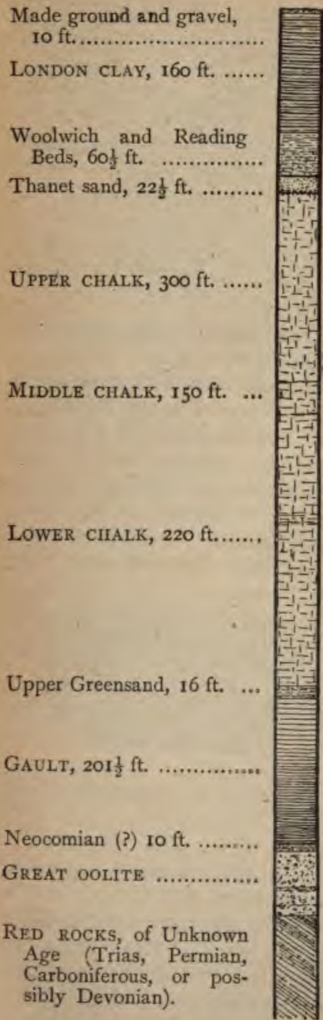

Fig. 126.
The Richmond Boring—a Vertical Section.

Fig. 127. Geology of the London Basin. Section from Shooter's Hill to near Plumstead Common.

illustrate. Such sections may be diagrammatic, in which case the vertical scale differs from the horizontal one, or true, as in Fig. 127, in which case the horizontal and vertical scales are the same. It is generally necessary to use diagrammatic sections, except when the district mapped is hilly and not extensive. In order to construct a horizontal section, it is necessary to know the general contour of the country and the positions of the strata. Where a stratum reaches the surface it is said to have an *outcrop*, or 'to outcrop,' and a geological map aims at showing all the outcrops, so that it gives the positions and extent of the strata at the surface of a country. The nature of the strata is determined by observation and indicated on the map by different colours.

Fossils are remains and traces of plants and animals found in the crust of the earth.—Objects are frequently found in stratified rocks which differ entirely from the sedimentary deposit in which they occur. Thus, a piece of shale may have upon it the remains of a fern-leaf, such as that shown in Fig. 107, and a close examination of it makes the fact apparent that the leaf must once have formed part of a living plant. Or shells and other remains, similar in appearance to those represented in Fig. 106, are found. These objects are called fossils. True fossils are those in which all the organic matter has decayed away and

Fig. 128. Bird-like footprints, from Turner's Falls in the Connecticut River, Massachusetts.

been replaced by mineral substances so that an exact model of the original body is preserved. But the term is also extended to apply to markings on sandstone resembling the ripple-marks often observed on the soft sand of a shelving beach, to foot-prints, to the little pittings produced by rain when the rock in which they occur was soft and moist, to burrows, etc. And often, instead of the original shell, bone, or other object being preserved, not a particle of it remains, but only 'casts' or hollow spaces showing the markings of the body previously enclosed in them.

(Fig. 128). Although fossils have been known for a very long time, their significance was not understood until about the beginning of this century. They were looked upon as curious objects, and classified with crystals, and were said to be the shells of animals which would subsequently be brought to life. Now, however, it is definitely known that they represent the remains of extinct plants and animals.

Fossils show the conditions under which the deposit of material in which they occur took place.—In general the animals and plants found in fresh water lakes and rivers differ from those which occur in the sea, although some fishes, *e.g.*, salmon, trout, &c., can live in either fresh or salt water. Similarly, some organisms live in shallow and others in deep water. Fossils are therefore classified according to their habitation during life. There are marine fossils; fresh water fossils; lacustrine fossils, representing animals which dwelt in lakes; fluviatile, or those that inhabited rivers; estuarine, which occur in the sand deposited in estuaries; and terrestrial fossils. The biologist is able to distinguish each of these forms from the other, hence, by utilising this knowlege, the geologist is able to learn something about the mode of formation of the rocks in which the fossils occur, and the conditions under which the organisms which they represent existed.

Fossils enable a stratum to be identified.—About the beginning of this century Mr. William Smith, a land surveyor, whilst engaged in cutting the canal between Bath and Bristol, observed that each of the different beds passed through was distinguished by certain fossils, so that it was possible to classify the strata by the fossils they contained. This being so, to determine whether a bed found in two different places was of the same geological age it is only necessary to make an examination of the fossils collected at each place. It must be at once understood, however, that fossils of the same geological age may be unlike each other, owing to the differences due to condition, previously alluded to. Thus fossils found in adjacent sandy and muddy banks may be very different, although they existed at the same period. Also, the climatic conditions being different over different portions of the earth, even at the same time, caused the forms of life to reach different stages of development. All that can be said then, when peculiar fossils are found in widely separated strata, is that the organisms they represent probably lived under similar *conditions.*

R

Fossils enable the relative ages of strata to be determined.—From the point of view of the naturalist, the lowest form of life was the first to appear on the earth, and from it have evolved in millions of years all the higher organisms. In general, in passing from older to newer strata the fossils change from lower to higher organisms, and, therefore, the older a rock the greater is the difference between the fossils found in it and the plants and animals existing at the present time. Certain fossil plants and animals occur only in certain strata, and are taken as type fossils of these strata. On the other hand, other species are found running through numerous strata, but occurring most abundantly in one of them. Fossils may be divided into three groups, viz., (1) Fossils of plants; (2) Fossils of vertebrate animals, that is, animals possessing a flexible backbone and an internal framework or skeleton, a true brain, and a spinal cord; this group includes fishes, reptiles, birds, and mammals; (3) Fossils of invertebrate animals, in which the characteristics of vertebrates are absent. Either of these groups can be used to mark geological time. It is found, however, that plants are not very satisfactory witnesses; invertebrate animals are much better; but probably the most reliable evidence of climatic and other geological changes is afforded by fossils of vertebrates.

Geological Periods.—Geologists classify the stratified rocks into periods according to their relative age, as indicated by fossils. The oldest rocks, in which life is unknown, are known by the name of *Archean*, or *Pre-Cambrian*. Then follow the *Primary* or *Palæozoic* (ancient life) rocks, which are divided for convenience into Older Palæozoic and Newer Palæozoic. The former period was essentially an age of invertebrates, and no vertebrate animals are known except in the uppermost strata. Very few fossil plants belong to this period. But when the Newer Palæozoic period is reached, vertebrates in the form of fishes are plentiful, and plants allied to the club-mosses and horse-tails of the present day are also found. In the succeeding *Secondary* or *Mesozoic* (middle life) rocks, plants are very abundant. Enormous reptiles also existed, but very few mammals. During the *Tertiary* or *Cainozoic* (recent life) period, the reptiles gradually diminished in size and in number, and became more like those of the present day. The higher organisms, both of plants and animals, became much more common. Each of these four great divisions represents enormous periods of time and great thicknesses of strata,

and are further subdivided into smaller *systems* or *formations*, as shown in the following table :—

Tertiary or Cainozoic (age of mammals)	Post-pliocene Pliocene Miocene Oligocene Eocene
Secondary or Mesozoic (age of reptiles)	Cretaceous Neocomian Jurassic Triassic
Newer Palæozoic (age of fishes)	Permian Carboniferous Devonian
Older Palæozoic (age of invertebrates)	Upper Silurian Lower Silurian Cambrian
(Life unknown)	Archean or Pre-Cambrian

Although the Archean rocks have been estimated to occupy something like one-half the known land surface of the globe, they cannot be subdivided, because all fossil remains, if any ever existed, have been effaced, and in nearly all cases metamorphism has completely obliterated the original stratification. It is extremely likely, however, that these rocks represent a period quite as long as that which has elapsed from the Cambrian to the present time.

Order of Succession of Strata.—It is hardly necessary to say that the formations shown in the preceding paragraph do not lie regularly upon one another from the Archean upwards like the coats of an onion. If this were so it would be impossible for us to know anything about the older rocks. In consequence of the movements which are continually going on in the earth's crust, the strata have been tilted up at various angles and sometimes occur vertically. These upheavals have brought the older rocks to the surface and enabled them to be investigated. But although the succession indicated in the table may be considerably interrupted by some intermediate beds having been worn away or accidentally disturbed, the order of the strata always remains unaltered, that is to say, Cretaceous rocks are always above Carboniferous, and Devonian, or Old Red Sandstone, below them, except in a few places where great disturbances have

forcibly caused an inversion of strata. This arrangement will be at once understood from an examination of a geological map of England. Roughly speaking, in travelling across England and Wales from Harwich to St. David's Head, we first meet with the clays, sands, and gravels belonging to the Tertiary system; these rest upon the Cretaceous rocks exemplified by the chalk downs of South-east England, whilst the Cretaceous in turn lie over the Oolitic limestones, shales, and sandstones of the Jurassic system, which occur in the Midland counties. Dipping under the Oolites is found the blue Lias, which stretches from Lyme Regis to Whitby in an irregular line, and then the red sandstones and marls of the Triassic system. The magnesian limestones of the Permian system pass under these and over the coal measures, millstone grits, and carboniferous limestones, which characterise the carboniferous period. The next formation consists mainly of a reddish coloured sandstone known as Devonian or Old Red Sandstone, and illustrated by rocks in Hereford and South Wales. The Upper and Lower Silurian and the Cambrian gritstones and shales pass under these in succession, and finally rocks of the Archean period are reached. This arrangement of systems of rocks one upon another is illustrated diagrammatically by the accompanying section. (Fig. 129.)

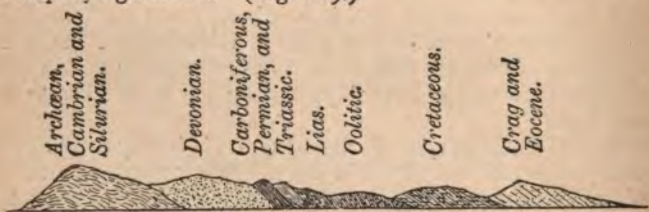

Fig. 129. General arrangement of British Strata.

QUESTIONS ON CHAPTER XIII.

1. What is the probable physical and chemical condition of the interior of the earth?

2. Name some characters impressed on rocks during their formation.

3. What rocks are formed by the consolidation of sands, clay, and shells, and how is the change brought about?

4. Give an explanation of the cause of the common hexagonal form of basalt columns.

5. What is meant by 'drawing to scale'? What is the difference between a diagrammatic and true illustration of an object?

6. Describe the general appearance of contour-lines on the Ordnance Survey Map of the district in which you live, and explain their meaning.

7. How can the relative ages of stratified rocks be determined?

CHAPTER XIV.

THE DEPTHS OF THE SEA.

The Seas and Oceans.—About three quarters of the whole surface of our globe, or 145,000,000 square miles, are covered with water. This enormous area is divided into several branches or compartments by masses of land, and a particular name has been given to each division, but really the water forms one continuous whole.

The following are the five great divisions of this water surface, with their distinctive names and general position relative to the continents :—

The Pacific Ocean, separating Australia and Asia from America.

The Atlantic Ocean, separating Europe and Africa from America —the Old from the New World.

The Indian Ocean lying between the Antarctic circle and the south of Asia and separating Australia from Africa.

The Arctic Ocean lying within the Arctic circle.

The Antarctic Ocean, lying within the Antarctic circle.

The first three of these oceans are great highways of traffic between the continents; the two remaining are not important in this respect, but in them, and in the former especially, a considerable amout of valuable whale fishery goes on.

The numbers contained in the following table will give an idea of the comparative size of these oceans :—

	Greatest Length miles	Greatest Width miles	Area sq. miles	Average depth miles
Pacific Ocean ...	9,000	12,000	67,000,000	3
Atlantic ,, ...	9,000	3,600	34,000,000	$2\frac{1}{2}$
Indian ,, ...	5,500	6,000	28,000,000	$2\frac{1}{4}$
Antarctic ,, ...	3,300	3,300	7,000,000	1
Arctic ,, ...	3,300	2,500	5,000,000	1

There is a much larger amount of water south of the equator than north of it. In the former we have the Antarctic, Pacific,

Indian, and Atlantic Oceans forming a belt completely surrounding the earth, and the land surface only occupying about one-third the area of that in the northern hemisphere.

Land and Water Hemispheres.—If we take a globe and set it so that London is at the top, it will be manifest that we shall be able to see a hemisphere of the globe, and inspection would show that most of it consists of land. The other hemisphere would be seen to consist almost entirely of water (Fig. 130). London, in fact, is nearly the centre of the land surface of the earth, and Antipodes Island, near New Zealand, is nearly the centre of the water surface.

The salts dissolved in sea water amount to $3\frac{1}{2}$ parts per 100 in ordinary sea water; hence, if we take 100 ounces of sea water and evaporate it we get about $3\frac{1}{2}$ ounces of solid matter left. In the case of an inland sheet of water, like the Dead Sea, the proportion of dissolved salts is much greater, being about 26·5 per cent. The percentage composition of the matter held in solution is shown in the following table:—

Salts.	Ordinary Sea Water.	Dead Sea Water.
Sodium chloride	2·73	7·75
Magnesium chloride	0·38	14·59
Magnesium sulphate	0·19	—
Calcium sulphate	0·13	0·07
Potassium chloride	0·07	0·65
Magnesium bromide	0·01	—
Calcium carbonate	0·01	—
Calcium chloride	—	3·10
Potassium bromide	—	0·32
	3·52	26·48

It will be seen that of the salts dissolved in ordinary sea water a little more than three-fourths consist of sodium chloride (common salt), the remainder being made up of various other substances, of which magnesium chloride, magnesium sulphate (Epsom salts), and calcium sulphate (gypsum), have the largest proportions.

All the streams that run into the ocean take into it a small quantity of earthy matter; it is, therefore, likely that the waters of the ocean have dissolved in them a small *quantity* of every element. It is found that the proportion of

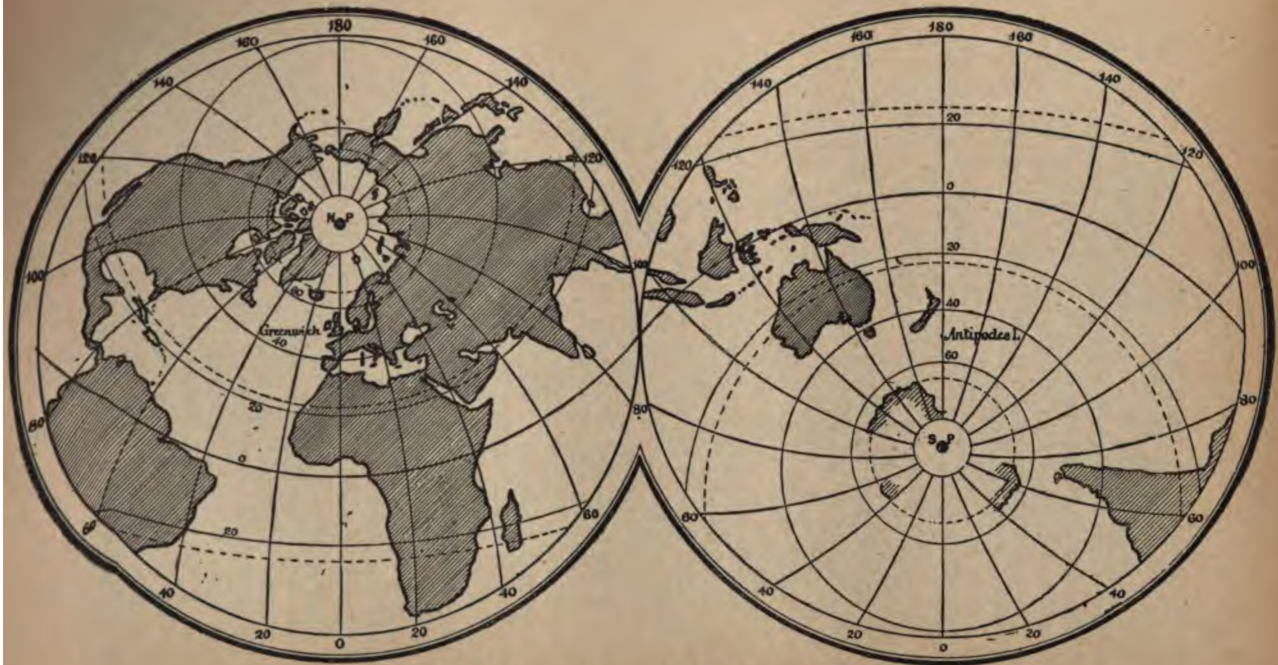

Fig. 130. Land and Water Hemispheres.

each salt present in sea water, with the exception of calcium carbonate, is the same whether samples be taken from the surface, or at a great depth. In the case of calcium carbonate the amount dissolved increases slightly with the depth, because the deeper water contains more carbon dioxide owing to the greater pressure, the carbon dioxide being produced by the decay of animals and plants, and in a much greater extent from the submarine volcanoes which exist at the sea bottom.

An idea of the magnitude of the dissolved salts may be obtained from the fact, that, if all the water in the ocean were evaporated, the layer of salts left on the ocean bed would be 170 feet thick.

The saltness of sea water varies very slightly. It does not depend upon the latitude or longitude of the place from which a sample is taken, and is not affected by depth. Local circumstances produce the slight variations which exist. Where the evaporation is in excess of rainfall,—as in the North and South Atlantic, owing to the trade-winds constantly blowing there,—the proportion of saline matter is increased. In the equatorial belt of calms the rainfall is in excess and the water is therefore comparatively fresher. And the water is also comparatively fresh in the Polar oceans, owing to the large amount of fresh water produced by the melting of ice. Similarly, the Irish Sea contains less dissolved salts than the Atlantic, because it is diluted by the rivers flowing into it. No part of the open ocean contains water as salt as in some inland seas, such as the Mediterranean, where the proportion of saline matter is 4 per cent., and in the Red Sea, where it is 4·3 per cent.

The constituents of the atmosphere are absorbed by the surface waters of the seas.—The gases dissolved form from 2 to 3 per cent. of the volume of the sea. Twenty-five per cent. of this consists of carbon dioxide, twenty-five per cent. oxygen, and the remaining fifty per cent. is nitrogen. Nitrogen and oxygen are believed to be entirely derived from the atmosphere. The nitrogen is fairly constant. Oxygen varies with the amount of oxidation, and with the amount of respiration by the submarine organisms it enables to live. The carbon dioxide plays a most important part, for water containing it in solution is capable of dissolving carbonates of lime and magnesia. Its production has been previously noted, and also the fact that it is most abundant towards the bottom of seas, in this respect *differing from* oxygen, which occurs in the greatest proportion at

the surface. A certain amount of *organic matter* brought down from the land by rivers, and resulting from the decay of animal and vegetable life, is also contained in sea water, and serves as food for some of the animals living in it.

The cause of the presence of dissolved matter in the sea depends to some extent upon the fact that streams and rivers are constantly bringing it down from the land. Evaporation is continually going on, that is to say, sea-water is continually losing pure water from its surface. The latter is eventually returned to the earth again in the form of rain or snow. Some of it falls upon the land surface, and reaches the sea again in the form of a stream or river containing another burden of dissolved salts. It would seem, therefore, from this fact alone, that the proportion of dissolved matter is increasing. But this action is hardly sufficient to account for the presence of the enormous quantity held in solution. It is now generally believed that at the time when many minerals which now ordinarily exist in the solid form were present in the atmosphere as heated vapours, hot rains occurred which brought down to the earth water strongly saturated with mineral matter derived from the atmosphere. This collected in the hollows and troughs of the surface of our then intensely hot globe, and formed the seas. The sea must, therefore, always have contained mineral matter in solution. The increase in the amount of dissolved matter in the ocean is mostly prevented by the requirements of the plants and animals existing in it.

Sea-water has a higher specific gravity than pure water.—Thus, if we take a bottle which contains 1 lb. of fresh water and weigh it full of sea water, we find the weight of the water is from 1·021 to 1·031 lbs. Hence the specific gravity of the sea water experimented upon is about 1·026. This is subject, however, to a slight variation. The highest specific gravity of water in the open ocean is 1·0278. This occurs in the centres of the systems of oceanic currents produced in the North and South Atlantic by the trade winds. The ocean water having the lowest specific gravity yet observed, viz., 1·0240, occurs in the Antarctic Ocean, and is doubtless due to the melting of polar ice.

The specific gravity of water from the Mediterranean Sea varies from 1·028 to 1·030, that of the Black Sea from 1·012 to 1·014, while that of the Dead Sea is 1·227. These variations depend upon the amount of matter in solution.

The specific gravity of sea-water increases slightly with the depth.—This is because water, although nearly, is not

absolutely incompressible. The water at great depths in the ocean is under enormous pressures, due to the mass of water resting upon it. The result is an increase of specific gravity as exhibited in the following table :—

Depth in Fathoms of the Water from which the Sample was taken.	Proportional Weight of Salt in 100 parts of the Water.	Specific Gravity.
0	3·5710	1·0247
50	3·5392	1·0275
100	3·5206	1·0278
200	3·4743	1·0289
300	3·4519	1·0297
400	3·4569	1·0307
1,900	3·4908	1·0525

It will be seen that the regular increase of specific gravity is not due to an increase in the proportion of dissolved matter, for this really suffers a decrease. Although the variation is extremely small it is most important, for if the water were not compressed at all, but existed as a mass uniform in specific gravity from top to bottom, the entire water surface would rise some 120 feet above its present level, and so submerge 2,000,000 square miles of the present land surface.

Methods of determining Ocean depths.—The old method of determining the depth of the ocean was by means of a heavy piece of lead attached to a rope, but on account of undercurrents the rope rarely went down vertically, and exaggerated results were obtained, which gave rise to the idea that in certain parts the ocean was 'unfathomable.' In all modern lines the weights, which are very heavy, are detached on reaching the bottom, and roll away. An apparatus used during the expedition of H.M.S, 'Challenger' (1872—76) is as follows :—A brass tube about two inches in diameter, and having a pair of valves opening inwards at the lower end, is attached to a sounding line of wire. An iron washer is held on the tube about 18 inches from the end by means of a wire sling, and on it rest three or four sinkers, each 56 lbs. in weight. When the sounding line has been paid out sufficiently, the tube strikes and is forced into the bottom of the ocean floor as far as the height of the
sinker. As soon as the sinkers touch
sling supporting them is thro
end of the tube ; t

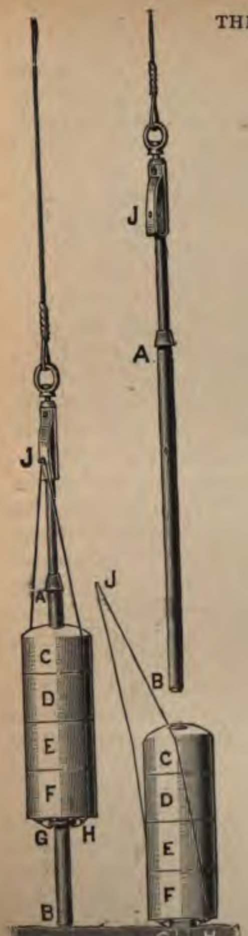

Fig. 131.

The Hydra Sounding Rod. A B is a hollow tube having a valve opening inwards at B. C, D, E and F are weights resting on the washer G H, which is kept in position by means of the wire sling at G J H. *When the washer touches the ocean floor the sling is thrown off and the tube is then drawn up.*

lessened, and the consequent slackening of the rate at which the line had been previously running out tells that the bottom has been reached. The tube, containing a sample of the ocean bottom, is therefore drawn up to the surface for examination, whilst the sinkers are left behind. (Fig. 131.)

The Continental Plateau.—The continents—three in the northern hemisphere, Europe, Asia, and North America, and three in the southern hemisphere, Africa, Australia, and South America—are simply masses of relatively high land, which, in the cases of Europe, Asia, and both Americas, rise gradually from the sea shore to the interior. They occupy about five-sixteenths of the surface of our globe. The bottoms of the great ocean basins cover about one-half the surface, and the sides leading up to the land now above sea-level fill up the remaining three-sixteenths. Much of the present land surface only represents the highest points of regions of land, all of which were above sea-level at some former time. And many seas, such as the North Sea, Black Sea, Mediterranean Sea, &c., are really but slight depressions in what was once a vast continent. In those days Great Britain was joined by dry land to the other parts of the European continent. This is indicated by the remarkable shallowness of the seas around the British Islands, and also by the similarity in constitution of the chalk cliffs of Kent and those of Northern France. Similarly, New Guinea was once joined to Australia. In fact, about 99 per cent. of the

whole land surface of the globe simply consists of protrusions above the level of the sea from what is well termed 'the continental plateau.' The remaining regions of elevation occur in detached areas, the largest of which lie in the Pacific Ocean and about the South Pole. The rocks which make up the numerous islands in the Pacific are entirely different, however, from those composing the greater part of the continents, and give reason to believe that these islands are the tops of old volcanoes through which molten rock was formerly ejected from the interior of the earth. Such cones are often capped with coral when rising nearly to the surface, and at a lower level are covered with the shells and skeletons of deep sea organisms.

The Depth of the sea seems to be on an average 2,000 fathoms, that is, about $2\frac{1}{4}$ miles. In some places, however, the depth is much greater than the average, and in others much less. The depths greater than 4,000 fathoms ($4\frac{1}{2}$ miles) are local, and seem usually to be pits in the earth's crust formed by volcanic action. All the oceans lie in great depressions, which occupy about one half of the surface of our globe, and run, to a certain extent, parallel with the axis of the neighbouring continent. The greatest depth in the Atlantic, 3,875 fathoms (nearly $4\frac{1}{2}$ miles), is situated to the north of Virgin Islands. In the Pacific the deepest part occurs to the south and east of Japan, where a sounding of rather more than 5 miles has been obtained.

The height of the continents is, on an average, approximately 1,000 feet above sea-level. We can thus determine the proportion of land above sea-level to the volume of water in the oceans. Using this estimation, the ratio of the volume of dry land to the volume of water is as 1 is to 41. The height of the highest mountain above sea-level is about 5 miles, and the greatest depth of the ocean is also about 5 miles. This inequality is comparatively insignificant, however, on a globe 4,000 miles in radius, like the earth. An idea of the amount of irregularity may be gathered from the fact that it would be represented on a globe 1 foot in diameter by a depression of $\frac{1}{60}$ of an inch.

The form of the sea-bottom is very different from that which characterises the land surface. After the depressions on the earth were converted into seas and oceans, the land above sea-level was battered and broken by copious rainfall and other agencies, and the disintegrated products carried into these waters by rivers. The same forces are working at the present time, and *as a result of* their action we see the sharp and bold ridges and hill

tops which make the earth's surface picturesque. At the sea-bottom these denuding forces do not exist. The ridges there are covered with deposit, smooth, and not much above the general level. Hill and valley occur as on the land, but all hollows get gradually filled up, so that the bottom appears like a vast undulating plain, varied here and there by a volcanic cone, which, rising above the surface of the water, forms a volcanic oceanic island, or by coral islands.

Remarkable inequalities in the bottom of the Atlantic.—If we travel from the west of Ireland to Newfoundland, and measure the depth of the water at various parts, we should find that the least depth was 1,750 fathoms, and the greatest 2,424 fathoms. The bed of the Atlantic between these points has few irregularities, and consists of extensive levels covered with a grey mud, which, on examination, is found to consist chiefly of the shells of the minute animalculæ found in abundance on the surface of the sea. This submarine plateau is known as the 'Telegraph Plateau,' because on it were laid, in 1865-66, the submarine telegraph cables between England and America.

Other submarine ridges or plateaus of relatively high level run along the ocean floor. They were formed in a similar manner to the continental plateaus—by the shrinking of the earth's interior and the consequent wrinkling of its surface. The water is of sufficient depth to submerge them at the present time, but in all probability these submarine plateaus were the surfaces of land in former times. They are more or less parallel to the axis of the continent near them. The soundings obtained during the Challenger expedition show that there is a ridge running along the middle of the Atlantic from Iceland to the Antarctic Continent. North of the equator it is known as the 'Dolphin Rise,' on account of some soundings made by the officers of the U. S. vessel 'Dolphin' in 1851. South of the equator it is called the 'Challenger' ridge or rise, and the portion joining these two is the 'connecting' ridge. Upon this ridge are situated the volcanic islands of the Azores, Ascension and Friendly Islands, St. Helena, &c. The average depth of water on the ridge is 1,500 fathoms, and the average depth on each side is 2,500 fathoms. The greatest depth obtained in the Atlantic was immediately north of the Virgin Islands, where there is a hollow 3,875 fathoms or nearly $4\frac{1}{2}$ miles deep. At this great depth the pressure of the water was nearly $4\frac{1}{2}$ tons on every square inch of surface, and the glass thermometers sent down to register the temperature were crushed under the enormous pressure. (Fig. 132.)

Section of the North Atlantic Ocean between Bermuda, Azores and Madeira.

Section of the North Atlantic Ocean between Sombrero and Teneriffe.

Section of the North Pacific Ocean between Japan and Admiralty Island.

Fig. 132.

Remarkable Inequalities in the Bottom of the Pacific.—The Pacific Ocean appears also to be divided by a submarine ridge running along its greatest length from North Chili to Japan. The bed of the North Pacific, however, differs considerably from that of the North Atlantic, inasmuch as it does not present extensive levels but is somewhat abruptly unequal. Captain (now Sir George) Nares, of the Challenger, sounded 4,575 fathoms (about 5 miles) near the Admiralty Islands at Papua, and Lieutenant Belknap, of the United States Ship 'Tuscarora,' reached 4,643 fathoms outside of the northern extremity of the ridge on which Japan stands, these two soundings being the greatest reliable ocean depths ever recorded. (Fig. 132.)

The action of the sea upon the earth's crust must have been noticed by every one who has seen waves dash against a sea coast. Large fragments of rock are loosened and fall into the water and are broken up and used to batter other portions; the rough fragments thus get smoothed and reduced to pebbles, and

Fig. 133. Illustration of the action of the sea in wearing away a coast line. (*From a Photograph by Wilson of Aberdeen.*)

then to sand. If the coast be steep, and the underlying rock relatively soft, the base of a cliff may be worn away until the weight of the overhanging top causes enormous masses of rock to break off and tumble into the sea below. Land-slips of this kind occur along the south coast of Devonshire and Cornwall. Some parts of a cliff are often softer than others, and so caves, channels, and creeks are formed, and if there are portions much harder than the general mass of rock, they are left as isolated outliers, needles, or stacks in the sea, while the coast-line is being worn away (Fig. 133). The process by which rocks are broken up is termed weathering, the loosened material is called *debris* or *detritus*, whilst the general work of disintegration and removal is termed *denudation*.

The nature of the material on the sea floor has been determined from examinations of the specimens brought up by sounding rods such as were used during the 'Challenger' expedition. From the land for about 200 miles the materials met with are sand, mud, &c., brought down to the sea by the rivers; but beyond this limit the deposit is of quite a different character; hence they have been divided into terrigenous or shore deposits, and abysmal or deep-sea deposits. These have been sub-divided by Dr. Murray in the manner shown in the following table:—

Terrigenous deposits	Shore formations Blue mud Green mud Red mud	Found in inland seas and along the shores of continents.
	Coal-mud and sand Volcanic mud and sand	Found about oceanic islands and along the shores of continents.
Deep-sea deposits	Red clay Globigerina ooze Pteropod ooze Diatom ooze Radiolarian ooze	Found in the abysmal regions of the ocean basins.

The blue, red, and green muds are found in the deeper water round continents and continental islands, and in enclosed or partially enclosed seas. They mainly consist of particles derived from the disintegration of rocks and carried down to the sea, suspended in the water of rivers. As the river loses its velocity the larger fragments are first deposited, finer pieces are carried further out into the sea before they sink and form a sediment, and the finest particles

may be carried out 200 or 300 miles before they settle on the sea floor. Green muds resemble blue muds in most respects. Red muds differ from these in containing a large proportion of ochreous matter. These sedimentary deposits represent a stage in the formation of shales, sandstones, and other stratified rocks for future epochs.

Volcanic muds and sands are produced by the disintegration of volcanic rocks, and occur around volcanic islands. They only differ from each other in the size of the particles of which they are composed.

Coral muds and sands occur near coral islands and shores fringed by coral reefs. They often contain 95 per cent. of carbonate of lime, made up of the remains of corals, lime-secreting algæ, foraminifera, mollusca and similar plants and animals. A large amount of amorphous matter occurs in coral muds. In coral sands there is a less proportion of this material and a larger proportion of remains of calcareous organisms.

Deep-sea deposits differ from those found near continents in the absence of the remains of continental rocks, the presence of numerous minute shells of organisms which have fallen to the sea bottom, and in an abundance of fine volcanic material, which has generally been much altered. The particles constituting continental muds get smaller in passing seaward from the coast, the shallow-water organisms gradually die out, and give place to those that flourish in the deep sea, so that the mud finally merges into a deep sea deposit.

Globigerina ooze is a fine soft mud, white, yellow, brown or red, according to the occurrence of oxides of iron and manganese. When dry it is like powdered chalk, and it has the same chemical constitution (carbonate of lime). It consists almost entirely of the dead shells of animals known as Globigerinæ, belonging to the group Foraminifera. The proportion of carbonate of lime may vary from 40 to 95 per cent., the remainder being made up of other compounds of lime, magnesia, iron, manganese, and silica.

Pteropod ooze only differs from Globigerina ooze in having a greater variety of shells of Foraminifera, and in the presence of the thin delicate shells of a species of deep-sea mollusc known as Pteropods.

Diatom ooze is a pale straw-coloured material composed chiefly of the remains of microscopic plants, called diatoms, that live on the surface of the ocean and secrete silica to build up their cells. When the plants die, the cells sink to the bottom of

the sea to form a deposit. About 25 per cent. of carbonate of lime usually occurs in diatom ooze in the form of Globigerina shells.

Radiolarian ooze consists of the minute shells of Radiolaria, animals having the property of secreting silica from sea water. The difference between Globigerina and Radiolaria lies in the fact that the former has a calcareous and the latter a siliceous shell. Globigerina ooze generally contains Radiolaria, so also does Diatom ooze. In some regions the deposit consists principally of the skeletons of Radiolaria with scarcely a trace of carbonate of lime. But in others the remains of Foraminifera make up as much as 20 per cent. of the ooze.

Red clay deposit characterises all the deepest parts of the ocean. Much of it represents the residue which results from the decomposition of the skeletons of calcareous organisms. In some of these clays, however, only a small proportion of silicate of aluminum may be present, the remainder consisting of minute mineral fragments and remains of siliceous organisms. The mineral particles mostly have a volcanic origin, and exist in a more or less altered condition. If a weak acid is added to an organic ooze a residue is obtained identical with that found on the ocean bottom. Near continents such a residue bears a small proportion to the carbonate of lime. Its relative abundance increases, however, with the depth and the distance from continents, until at great depths calcareous organic remains are absent, and the residue predominates. The organic and the red clay deposits thus pass one into the other. The latter deposits generally contain a number of minute specks of iron and manganese, which doubtless represent the remains of some of the 400,000,000 meteoritic particles that fall upon the earth every twenty-four hours. Sharks' teeth, the ear bones of whales, and portions of the bones of other marine animals also occur in red clays embedded in thick coatings of oxides of iron and manganese—compounds which give the clays their characteristic brownish or red colour.

The distribution of organic oozes and red clay is summed up by Dr. Murray as follows: 'The organic oozes and red clay are confined to the abysmal regions of the ocean basins. A Pteropod ooze is met with in tropical and sub-tropical regions in depths less than 1,500 fathoms; a Globigerina ooze in the same regions between the depths of 500 and 2,800 fathoms; a *Radiolarian* ooze in the central portions of the Pacific, at depths

greater than 2,500 fathoms; a Diatom ooze in the southern ocean south of the latitude of 45° South; a red clay anywhere within the latitudes of 45° North and South, at depths greater than 2,200 fathoms.'

All the forms of life found in the ocean are most numerous near to the continental plateau, where there is shallow water and abundance of food in the shape of calcium carbonate and silicon brought down by the rivers. Another reason why the number should diminish with the distance from the continental plateau is that in all probability all deep sea animals have their origin in shallow water and have migrated oceanwards. At a depth of half a mile there are no plants, but still numerous animals. At a mile or more the majority of the animals met with are of an entirely different species from those near the surface; the same species of animals are found, however, in all the oceans at about the same depth.

The estimated area covered by the deposits, the mean depth at which they occur, and the mean percentage of carbonate of lime in them is tabulated below:—

		Area in square miles.	Mean depth in fathoms.	Mean per centage of carbonate of lime.
Oceanic Oozes and Clay	Red clay	50,289,600	2,727	6·70
	Radiolarian ooze	2,790,400	2,894	4·01
	Diatom ooze	10,400,600	1,477	22·96
	Globigerina ooze	47,752,500	1,996	64·53
	Pteropod ooze	887,100	1,118	79·26
Terrigenous Deposits	Coral sands and muds	3,219,800	710	86·41
	Other terrigenous deposits, blue muds, &c. ...	27,899,300	1,016	19·20

Calcareous shells do not accumulate at great depths in the ocean, although the lime-secreting organisms may be as numerous on the surface as in shallower waters. The absence is accounted for by the fact that at great depths the sea water, on account of the great pressure, contains a greater amount of dissolved carbon dioxide than the water at higher levels. The carbonate of lime, therefore, of which the shells are composed, is dissolved and passes into solution before they reach the bottom; at depths not quite so great, the thinnest shells are

dissolved and the coarsest only are deposited. Siliceous shells can of course exist at all depths in the ocean.

The decrease in the percentage proportion of carbonate of lime with increased depth is exhibited in the last column of the foregoing table. The shells of Pteropods and the more delicate Foraminifera occur very abundantly in deposits from depths between 700 and 1,000 fathoms, whilst only traces of the same shells are found between 1,800 and 2,000 fathoms, and at depths of 3,000 fathoms or more the carbonate of lime may be said to disappear entirely. Indeed, quartz-sand, pebbles, and greensand appear to be the only minerals which preserve their integrity at the bottom of the ocean; felspar and mica are rarely found. The abysmal muds consist very often of the finest sand with some mica flakes, and just sufficient clay to produce cohesion.

A comparison of terrigenous deposits with sedimentary rocks indicates that the two formations have had similar origins. The material deposited on the borders of continents and continental islands, and in enclosed seas, is of the same kind as that which makes our chalks, sandstones, conglomerates, shales, and other sedimentary rocks, and it only requires to be hardened by pressure, and raised above sea-level, to form a solid land surface. We have shown that these necessarily slow movements of elevation and subsidence are continually going on, hence it is concluded that the sedimentary rocks of the present continents were originally deposited beneath the surface of the sea around former continents, and afterwards elevated to their present position, whilst other portions of the continents subsided. Such changes are constantly occurring, and so the form and size of all continental areas are always varying.

QUESTIONS ON CHAPTER XIV.

1. How is the depth of the ocean determined? (1888.)
2. What are the chief substances present in solution in the waters of the ocean, and whence are they derived? (1887.)
3. What do you know concerning the animals which inhabit the deepest parts of the ocean? (1885.)
4. What is globigerina ooze, and where is it found? (1882.)
5. What is the average specific gravity of sea-water? What causes the slight variations of specific gravity of water from different depths and different places?
6. *Describe* some remarkable inequalities in the bottom of the Atlantic *and Pacific Oceans.*

7. What is the probable origin of the red clay deposits found over the ocean bottom?

8. What is the chief difference between the chemical composition of Globigerina ooze and of Radiolarian ooze?

9. What are the average and greatest heights of the land surface and the average and greatest depths of the ocean?

CHAPTER XV.

THE TEMPERATURE AND MOVEMENTS OF THE SEA.

Measurements of the temperature of the ocean at the surface and at great depths have been made during the 'Challenger' and other expeditions, by means of self-registering thermometers, constructed to resist the enormous pressures to which they may be subjected, and to register the temperature at the bottom or any required depth. In deep soundings a series of thermometers is often fixed upon the sounding line at known distances apart, and the temperature of various layers of water thus determined. The thermometer which seems to give the best results in researches on deep-sea temperatures is made by Messrs. Negretti and Zambra, the well-known instrument makers. The form of the bulb and stem is shown in Fig. 134. If the instrument is held bulb downwards, and subjected to a temperature of say 40° C., the mercury in the bulb expands and fills the tube and part of the reservoir C at the top. And if the thermometer is then held bulb upwards, the mercury breaks off at the part A, where the tube is contracted, and by its own weight flows down the tube, filling C, and a part of the tube above. The scale reads upwards from C, and the temperature is therefore indicated by the top of the mercury in the tube. To set the thermometer the bulb is held downward. When the existing temperature is required all that has to be done is to turn the bulb upward and keep it in that position until the reading is taken. This being so, the temperature of the sea at any depth can be determined, if it is possible to cause the thermometer to turn over when the sounding-line has been paid out to the required length. How this condition *is fulfilled,* and the instrument is prevented from accidentally

turning over, can be understood by the enquiring student from Negretti and Zambra's own description, contained in the note at the bottom of this page* in connection with Figs. 135 and 136.

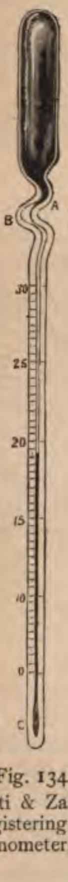

Fig. 134.
Negretti & Zambra's self-registering Thermometer.

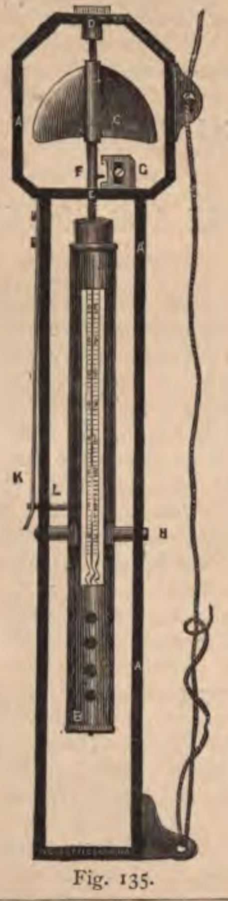

Fig. 135.

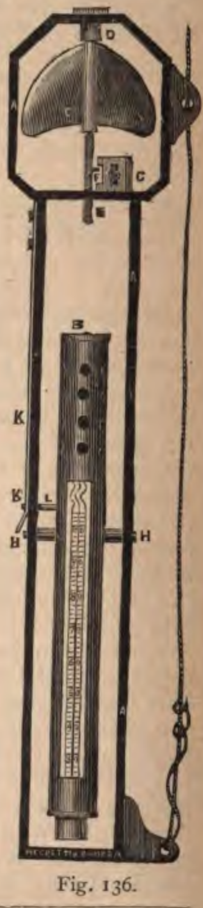

Fig. 136.

* A is a metallic frame in which the case B, containing the thermometer, is pivoted upon an axis H, but not balanced upon it. C is a screw-fan attached to a spindle, one end of which works in a socket D, and on the other end is formed the thread of a screw E, about half-an-inch long, and just above

The surface temperature of the sea in the tropics and sub-tropics is from 60° F. to 80° F., and sometimes 85° F. or 86° F. is reached near the equator. There is a general decrease from these regions to the poles where the average temperature is about 30° F.

The difference between the temperature of the surface water at the equator and at the poles is due to the fact that the sun only shines obliquely at the poles but is almost vertical at the equator all through the year. Again, since the sun is vertical over the tropic of Cancer in June and then travels southwards and is vertical over the tropic of Capricorn in December, the waters of the two hemispheres are subject to an annual variation. And on account of the low radiating power and high specific heat of water the highest temperature is reached not in June but August in the Northern Hemisphere, and the lowest in February. The annual variation, however, is very small at the equator and poles but in the temperate zones it may be as much as 10°. This is about the annual variation in the temperature of the sea around Britain. The difference of temperature of the land surface of the globe during the hottest and coldest times of a day is very considerable.

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it is a small pin or stop F on the spindle. G is a sliding stop-piece against which the pin F impinges when the thermometer is adjusted for use. The screw E works into the end of the case B, the length of play to which it is adjusted. The number of turns of the screw into the case is regulated by means of the pin and stop-piece. The thermometer in its case is held in position by the screw E, and descends into the sea in this position (Fig. 135), the fan C not acting during the descent because it is checked by the stop F. When ascent commences the fan revolves, raises the screw E, and releases the thermometer, which then turns over and registers the temperature at that spot, owing to the axis H being below the centre of gravity of the case B as adjusted for the descent. Each revolution of the fan represents about 10 feet of movement through the water upwards, so that the whole play of the screw requires 70 or 80 feet ascent; therefore, the space through which the thermometer should pass before turning over must be regulated at starting. If the instrument ascends a few feet by reason of a stoppage of the line while attaching other thermometers, or through the heave of the sea, or any cause whatever, the subsequent descent will cause the fan to carry back the stop to its initial position, and such stoppages may occur any number of times, provided the line is not made to ascend through the space necessary to cause the fan to release the thermometer. When the hauling in has caused the turn over of the thermometer the lateral spring K forces the pin L into a slot in the case B and clamps it (as seen in Fig. 136), until it is received on board, so that no change of position can occur in the rest of the ascent from any cause. The case B is cut open to expose the scale of the thermometer, and is also perforated to allow the free entry of the water.

But in the case of the surface water of the sea the daily variation does not exceed 1° F. The water affected directly by the sun's rays is in all cases only a comparatively thin layer on the surface. At a depth of about half a mile at the tropics the temperature falls to 40° F., and there is little or no change from this point to the bottom, where the water is ice-cold. In fact the great mass of sea water has a temperature of 40° or less.

The temperature of the ocean decreases with the depth.—In the open ocean the fall of temperature from the surface is at first very rapid and then slow until about 40° F. is reached at a depth which varies from about 300 to 900 fathoms. This general decrease is exhibited graphically in Fig. 137, which shows some soundings obtained between Bermuda and New York by the Challenger expedition, and *isotherms* or *isothermal lines*, indicating the layers of water having the same temperature. To quote the report, 'In the section from Bermuda towards New York eight soundings, seven temperature soundings, and four dredgings were obtained. The bottom temperature, at depths exceeding 1,800 fathoms, was again remarkably uniform, from 36·5° to 36·8°, the mean being 36·6°, nor was it affected in any way by the cold surface water on the north-west side of the Gulf Stream. The isotherm of 40° was found at a uniform depth of 810 fathoms for 350 miles N.W. of Bermuda, but after crossing the Gulf Stream it rose to 280 fathoms. The other isotherms maintained a position parallel to that of 40°.'

Submarine elevations affect the temperature by cutting off a body of water from the ocean and thus preventing the free movement which goes on along the floor. Hence, where such ridges exist, the temperature may remain uniform for some distance from the bottom. A good example of this occurs in the Strait of Gibraltar, where the depth of the water is not more than 200 fathoms. The result is that the only water which can enter the Mediterranean from the Atlantic is that which has a temperature higher than 54° F., and can flow over the ridge. The colder, and therefore specifically heavier, water is effectually barred out by the ridge. Hence it is found that beyond a depth of about 120 fathoms in the Mediterranean the water has a uniform temperature of 54° F., and does not decrease progressively as in the open ocean.

The temperature of the water below 500 fathoms *in the open ocean* appears to be never higher than 40° F. Since, *however*, the temperature of the surface water at the equator

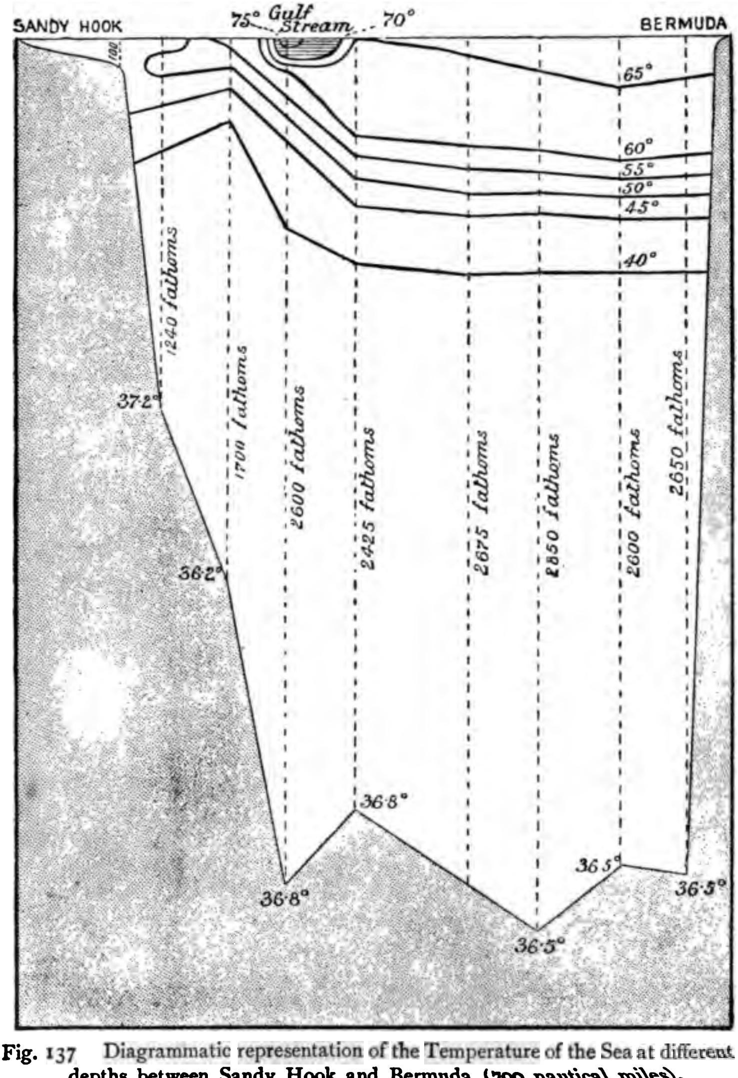


Fig. 137 Diagrammatic representation of the Temperature of the Sea at different depths between Sandy Hook and Bermuda (700 nautical miles).

is 80 degrees, there is a tendency for the deeper water at the equator to be much hotter than water at the same depth at the poles; but observations prove that this is not the case, and therefore the cold bottom water at the equator must have come from the frigid zones. The deep sea currents of cold water do not flow in equal volumes from the Arctic and Antarctic Oceans to the equator. The configuration of the land in the latter ocean offers every facility for the flow of such currents towards the north, whereas the only places where the Arctic water can flow towards the south are between Europe and America, into the Atlantic and through Behring Strait into the Pacific. Sounding observations have demonstrated the existence of the 'telegraph plateau' between Europe and America, a submarine ridge which rises to within 500 fathoms of the surface of the water, hence the creep of cold bottom water from the Arctic into the Atlantic is prevented at this point, and such water can only flow towards the equator through the Behring Strait and the narrow channels between Iceland and Labrador. The result of this obstruction is that the cold bottom water as far north as the 40th degree of latitude comes from the Antarctic Ocean. No better description of this could be found than that given by Sir George Nares, of the 'Challenger,' who, in his remarks on the temperature of the water in the North Atlantic between the equator and the 40th degree of latitude, says:—'Below the water immediately affected by the solar heat, which appears to be only the upper 60 or 80 fathoms, all the water in the North Atlantic, as far north as the 40th degree of latitude, is warmer than that at the same depth at the equator. . . . . . . There being water of a temperature of 32·4° at the equator, with warmer water at all stations north of it, proves conclusively that the cold water at the bottom of the Atlantic, as far north as the Azores, 38° N., and Bay of Biscay, 48° N., equally with that at the equator, is derived from an Antarctic and not from an Arctic source; for if at the equator the water supplied from the southward retains its cold temperature to so great an extent, the bottom water of the North Atlantic, if supplied from the nearer Arctic Sea, should be at least as cold: but the temperature of the lowest stratum increases decidedly as we pass north, and completely cuts off the Arctic water found at the bottom of the Faroe Channel by the "Porcupine" from that we have discovered at the equator.

'On the western side of the Atlantic, at all the stations south of the Bermuda and Azores lines, the bottom water is colder than on

the east side, showing that the Antarctic cold current enters the North Atlantic and runs to the north-westward through the channels between St. Paul's Rocks and the Brazilian coast, and gradually expends itself as it circles round to the north-westward, in the same manner as the warm equatorial current does on the surface, considering that current as including the Gulf Stream, which it undoubtedly helps to produce.'

The Great Equatorial Current is a broad stream of warm water lying north and south of latitude 6° N., and flowing in a westward direction.

When the stream of water strikes the eastern shores of Africa, or America, or the islands of the East Indian Archipelago, it is broken up, some being caused to flow towards the north, and some towards the south. But in accordance with the law that, if a body is moving from the equator there is a force arising from the earth's rotation which deflects it to the east, the northerly current is deflected towards the right hand, that is, east, strikes the western shores of one of the continents, and is turned again into the great equatorial stream; a sort of enormous vortex of water is thus formed, rotating in the same direction as the hands of a watch.

The portion of water deflected towards the south deviates to the left hand, that is, also to the east, because of the rotation of the earth, strikes the western shores of one of the continents, and is caused to flow into the equatorial current like its northern counterpart. Hence in the southern hemisphere the vortex motion is in the opposite direction to the hands of a watch. Since, therefore, there are three land masses to deflect the equatorial current, there should be six great systems of oceanic circulation, three right-handed vortices of water in the northern hemisphere, and three left-handed vortices in the southern hemisphere.

The chief currents formed in this manner are enumerated below, and their positions will be found on Fig. 138.

The Great Surface Current Systems caused by the breaking up of the equatorial currents are :—

(1.) The right-handed vortex in the North Atlantic Ocean called the Gulf Stream.

(2.) The left-handed vortex, of which the Brazil current *is part*, circulating in the South Atlantic Ocean.

Fig. 138. Surface Currents of the Oceans.

(3.) A right-handed vortex in the North Pacific, giving rise to the Japan current.

(4.) A left-handed vortex in the South Pacific, of which the New South Wales current forms a part.

(5.) A left-handed vortex in the South Indian Ocean, of which the Agulhas current forms a part.

The centre of each oval whirl of water is comparatively still, and over a considerable area of such water surface grow dense masses of a rootless seaweed termed *sargassum bacciferum*. The parts of the oceans where the growth occurs are known as Sargasso Seas.

The Best known Cold Surface Currents are :—

(1.) The Labrador and East Greenland currents flowing from the Arctic Ocean to the Atlantic.

(2.) Humboldt's current flowing, from the Antarctic Ocean, in a north-east direction to South America, and into the south equatorial current of the Pacific.

The Theories of Oceanic Circulation are :—

(1.) That the impulse of the prevailing winds of the globe on the surface of the oceans produces a movement of the upper layers which is transmitted through the entire mass of water.

(2.) That the difference of temperature of equatorial and polar regions causes a difference of specific gravity, and a general movement of warmer and lighter surface water from the equator to the poles, and colder and heavier bottom water from the poles to the equator.

(3.) That unequal evaporation causes difference of saltness of the waters of the ocean, and therefore a difference of specific gravity, which produces a sinking of the denser water to a lower level and a movement of lighter and fresher surface water to take its place.

Explanations of the Theories.—(1) When the effect of the wind in causing waves and obstructing tides is considered, it is not difficult to understand that a constant wind may drive the water of the oceans before it. In fact a working model, devised by Mr. A. W. Clayden, which may be seen in the western galleries of the South Kensington Museum, illustrates this exceedingly

well. It consists of a model of the Atlantic, in which the seas are represented by the surface of some water over which a very light powder has been scattered. A foot blower is attached, and when it is worked a gentle blast of air is delivered from a number of tubes in such a way as to set up a circulation of air resembling that of the atmosphere over the real ocean. These imitation prevalent winds act upon the water and create a system of currents resembling those of nature. The Gulf Stream may be seen issuing from the Gulf of Mexico, and the return current flowing eastwards between the two great equatorial currents, whilst the Labrador current flows from Baffin's Bay. The model is constructed so that portions of Central America are made removable, and when such a removal is made, the flow of the Gulf Stream is altered and fails to reach our shores. But, although it is easy to understand this explanation of surface currents, it is not so easy to understand how the motion of deeper water is affected and the deep sea circulation is kept up by such a movement. This theory, however, is held by many eminent geographers. In the words of the late Dr. Croll, 'Much of the difficulty experienced in comprehending how under-currents can be produced by the wind, or how an impulse imparted to the surface of the ocean can ever be transmitted to the bottom, results, to a considerable extent at least, from a slight deception of the imagination. The thing which impresses us most forcibly in regard to the ocean is its profound depth. An average depth of, say, three miles produces a striking impression; but, if we could represent to the mind the vast area of the ocean as correctly as we can its depth, *shallowness* rather than *depth* would be the impression produced. We should call a sheet of water one hundred yards in diameter and one inch in depth a very *shallow* pool; in fact we should speak of it as simply a piece of ground covered with a thin layer of water. Yet such a thin layer of water would be a correct representation in miniature of the ocean; for the ocean in relation to its superficial area is as shallow as the pool of our illustration. In reference to such a pool or thin film of water, we have no difficulty in understanding how a disturbance on its surface would be transmitted to its bottom, and if we could form as accurate an impression of the vast area of the ocean as we do of such a pool, all our difficulty in understanding how the impulses of the wind acting on the vast area of the ocean should communicate motion down to its *bottom* would disappear.'

(2) According to this theory, the water at the equator is lighter than that in colder regions, and therefore stands at a higher level. There is a gentle slope thus formed from the equator to the poles, and this causes a general movement of the upper warm layers of the ocean from the equator to the poles, and a counter movement of the under cold layers from the poles towards the equator; the direction of the movement in each case being, of course, modified by the earth's rotation. Much can be said in support of this theory, for as long as the equator receives more heat from the sun than the poles, so long must tropical waters expand and become specifically lighter than those in the temperate and frigid zones, and so long must convection currents be set up, and warm surface currents and cold under-currents exist.

(3) On account of the greater amount of evaporation at the tropics than at the poles, the tropical waters contain a greater proportion of dissolved salts, and are therefore specifically heavier than the polar waters; hence the surface water at the tropics, as it becomes heavier owing to the evaporation, sinks to the bottom, and fresher and lighter water flows in, takes its place, and maintains equilibrium. The downward movement thus produces a circulation. A good example of this kind of circulation is afforded by the Mediterranean Sea, where less water falls than is evaporated from its surface. But the water of the Mediterranean does not increase in saltness, and therefore fresher water must flow into it from the surrounding ocean. In fact it has been proved that a surface current flows from the Atlantic Ocean through the Straits of Gibraltar into this sea, and that a very salt under-current flows outwards into the Atlantic. And this circulation is evidently due to the difference of specific gravity of the water in the enclosed sea and that of the ocean water which feeds it.

It appears most probable, however, that oceanic circulation is not primarily caused only by the impulse of the wind, by the unequal heating of the waters on the globe, or by the difference of density arising from excessive and unequal evaporation, but is the result of all these causes.

The freezing point of sea-water is about 27° or 28° F., whereas fresh water congeals at a temperature of 32° F. During winter in the Arctic and Antarctic Oceans large areas of the sea surface get frozen over. First, thin flakes of ice known as *sludge* are seen, and finally an *ice field*, that is, a large expanse of ice, is formed. Such an expanse is broken and covered with hummocks,

snowdrifts, and fissures. Towards the end of the winter the ice fields begin to break up into *ice-floes*, or ice islands, a group of them being called *pack ice*, whilst a part is often broken up into smaller masses, known as *drift ice*. The shelf of ice that forms along the shore by the freezing of sea water is known as the *ice foot*. The formation often breaks off during the summer, and carries the *débris* from cliffs overhanging the shelf to distant regions. Of this we shall speak later.

A Glacier is a River of Ice.—At a certain height above sea level, which, however, varies in different latitudes, there is a region where the moisture is always precipitated in the form of white powdery snow. In England the snow quickly disappears by melting or evaporation. In the region of perpetual snow, although there is still a loss by evaporation, there is none by melting, hence an accumulation occurs; the first layer of snow has another layer piled upon it, and so on for many other layers. The result of this accumulated weight is that the snow becomes very compact, for the same reason that fleecy snow-flakes when pressed together form a compact snowball, and the reason in each case is that the air has been squeezed out. The pressure increases with successive falls, and eventually the lower layers become so compressed as to be transformed into ice. At the bottom blue transparent ice would be found, at the top fine granular snow. If the layers of snow rested on a level plain and in the region of perpetual snow, the accumulation would reach a thickness of thousands of feet; indeed, it is believed that in the Antarctic regions the thickness of the whole layers amounts to more than 10,000 feet. Such sheets of snow are called *snow fields*. If a snow field is formed on a slope there is a constant tendency for the mass to slide downwards. The valleys leading up into the snow field become filled with compact snow called *névé* or *firn*, and the pressure of the upper layers combined with the pressure at the side of the valleys transforms these tongues into moving rivers of ice, which creep gradually down from the region of perpetual snow, by the action of gravity. Such a river of ice is called a glacier.

Icebergs represent the discharge of Glaciers, and consist not of frozen Sea-water but of Land-ice.—When a glacier meets a lake or the sea, large masses of it break off and float on the surface of the water until they melt away. All such *floating masses* are called *Icebergs;* and since a glacier is formed primarily from snow, all such mountains of ice are fresh.

Sometimes the glacier is pushed out at once into deep water, and huge fragments are broken off on account of the buoyancy of the ice (Fig. 139), at other times it is pushed along the sea bottom for some distance. Everyone knows that ice floats on fresh water, much more then does it float on sea water, which is heavier, bulk for bulk, than fresh water at the same temperature. Only about one-ninth of the bulk of an iceberg floats above water, the other eight-ninths being below the surface. It sometimes happens that the part of the iceberg in the water is wasted away quicker than

Fig. 139. Formation of Icebergs.

the visible portion, the result being that the iceberg gets 'top heavy,' and turns right over. A difference between an iceberg and an ice-floe is that the former often carries blocks of rock into the sea and the latter, being of marine formation, transports no such materials. As the iceberg melts its *débris* is dropped into the sea and deposited upon the sea bottom, this affording an example of how material is conveyed from one place to another.

Icebergs have been met in latitude 70° N., carrying beds of earth and rock, which were estimated to weigh from 50,000 to 100,000 tons.

A description of ice and icebergs seen in the Antarctic Ocean is given by Sir George Nares in one of his 'Challenger' reports. (Fig. 140.) He writes :—'The icebergs met with by us were usually from a quarter to half a mile in diameter, and about 200 feet high; the highest measured was 348 feet high, but it was evidently an old berg floating on a large base; the largest was seen furthest south in latitude 66° 40′, it was certainly three miles in length, and was accompanied by several others nearly as large.

Fig. 140. Iceberg and part of a Polar Ice-field.

'They were all remarkably clear of rocks or stones, although each time we have dredged sufficient evidence was brought up that the bottom of the sea is fairly paved with the *débris* brought by them from the Antarctic lands.

'In shape they were very nearly tabular, the original top surface of the glacier remaining uppermost, or inclined at a slight

angle to the horizon; in this cold climate they could not be otherwise unless they broke up in consequence of some local weakness. . . . . The pack-ice consisted chiefly of small salt water ice pieces—they cannot be called floes—from 30 feet to 50 feet in diameter; 100 miles inside the pack-edge Ross found them to be 200 yards in diameter. The single season's ice was about 3 feet in thickness; the hummocky ice formed by several layers of this heaped one upon another and frozen compactly together, was from 7 feet to 8 feet thick, the upper surface of each piece being covered by a layer of snow about a foot in thickness. Scattered about in the pack were a few blue-coloured berg pieces of all sizes, some of them frozen into the salt water ice. All the latter were much honey-combed by melting, but it was evidently still of sufficient strength to give a very dangerous blow if accumulated against a ship's side, or to a vessel forcing her way through the pack. A properly fortified ship could have made way through most of what we saw, and it certainly does not deserve the name of a "barrier" given to it by Wilkes, although he was perfectly justified with his unfortified ship in keeping outside it.

'In the pack were numerous icebergs, but they were not in greater numbers than we found in the open water, and certainly not numerous enough by themselves to create the nucleus for the pack to form upon.

'When at the pack-edge the temperature of the water was always between 28° and 29°, just sufficiently warm to melt salt water ice very slowly, but to have no effect on the fresh water berg pieces. At a short distance from the pack the surface water rose to 32°, but at a depth of 40 fathoms we always found the temperature to be 29°; this continued to 300 fathoms, the depth in which most of the icebergs float, after which there is a stratum of slightly warmer water of 33° or 34°.'

The climate of a place is the average of the weather conditions.—It depends upon various causes, one of which is the mean annual temperature and the range of temperature. The average summer and winter temperatures of any particular locality vary very little from year to year, hence there is a practically constant difference between the temperatures at these two seasons, and this difference is called the *annual range of temperature*. The difference between the temperature in the day and night is called the *diurnal range of temperature*.

The situation of a place with respect to the sea is of considerable importance in determining its climate.— All water surfaces tend to equalize temperatures, that is, tend to render a climate less hot in summer and less cold in winter. Hence, in a district near a water surface, the range of temperature is small and the climate is temperate, or, as it is more often termed, *oceanic or insular*. A truly oceanic climate occurs on such small islands as are found in the Pacific, where the temperature only varies about five or six degrees throughout the year. An insular climate is exemplified by Great Britain and Tasmania,

Fig. 141. Isothermal lines showing places that have the same average yearly temperature.

where the range of temperature is 20°. The influence of water surfaces upon climate is exemplified in Fig. 141, which gives the *isothermal lines*, or lines of equal temperature. These lines join those places that have the same average yearly temperature. It will be seen that in the Southern Hemisphere the preponderance of water surface causes the isothermals to be distributed with much regularity according to the latitude, whereas the irregular distribution of land and water in the Northern Hemisphere causes the lines to be very irregularly distributed. In contradistinction to places whose climate is tempered by water, there are large

tracts of land where no such modifying influence exists, where there is a wide range of temperature—a climate of extremes. These localities are therefore extremely hot in summer and severely cold in winter, and are said to have a *continental climate.* Thus in the interior of the United States the range of temperature is from 30° to 60° greater than places in corresponding latitudes on the Pacific coast, and although Moscow has the same latitude as Edinburgh the average difference between the summer and winter temperatures at the latter place is 19 degrees and at the former 49 degrees.

Ocean currents exert a considerable influence on climate, a cold current lowering the temperature of the coast near which it passes, a warm current raising it. Hence the east coasts of South America, Africa, and Australia, towards which the warm equatorial current flows, are warmer than the west coasts. In the northern continents, however, the west coasts are much warmer than the east coasts on account of the cold currents which run along the east coast from the Arctic Ocean. Thus the cold Labrador current lowers the temperature of Newfoundland and New York and other places on the east coast of North America. Places on the opposite side of the Atlantic in the same latitudes have much warmer climates because of the influence of the warm Gulf Stream drift; for, although the Gulf Stream proper does not exist further north than the latitude of Newfoundland, the warm waters drifted by it affect the climate of the whole of north-west Europe. The winter temperature of London due to its position on the globe is about 17°, and that of Shetland 3°. On account of the Gulf Stream, however, the former has a mean winter temperature of 37° and the latter of 39°. The influence of the stream is also well marked by the mild climate of the Faröe Islands, situated in latitude 62°, that is, several hundred miles north of Scotland; and Dr. Haughton concludes that 'The effect of the Gulf Stream upon the climate of Spitzbergen at present is to raise its mean annual temperature 11·5° Fahr.' Hence if any alteration of the present form of the land should occur to prevent the flow of the warm water of this stream into the North Sea it is evident that the climate of Norway and the British Islands would be affected.

QUESTIONS ON CHAPTER XV.

1. What is a glacier? Where do the materials come from? What becomes of the materials? (1884.)

2. Describe the mode of origin of icebergs. (1878.)

3. What are the differences between continental and insular climates, and how are these differences caused? (1877.)

4. Draw a sketch-map of the Atlantic Ocean, and indicate upon it the courses of the chief of the great currents. (1877.)

5. Describe briefly a thermometer for determining the temperature of the sea at any depth.

6. What is the average temperature of the sea in torrid, temperate, and frigid zones respectively, and what are the main variations?

7. How does the temperature of the ocean vary with the depth?

8. What are the great systems of surface currents of the oceans. Give an explanation of the cause of the movement of water.

9. What is an ice-floe and an ice-foot, and how do they differ?

10. State roughly the course of the Gulf Stream, and the cause of its formation. How does it affect the climate of the British Isles?

CHAPTER XVI.

THE PRESSURE AND COMPOSITION OF THE ATMOSPHERE.

Determination of the weight of Air.—When the wind blows we are made conscious of the presence of an invisible something surrounding us in all directions; lightnings flash, thunders roll, torrents of rain, hail, and snow fall upon the surface of our globe, and the region where all these things occur is called the atmosphere, that is, the vapoursphere. Since this mass of matter has a material existence, it must have weight, although previous to 1650 no one had demonstrated the fact. The method adopted in the determination of the weight of air is illustrated by Fig. 142. A globe of glass having a capacity of, say, a cubic foot, has the air pumped out of it and is weighed; the stop-cock is then turned and air rushes in and fills up the globe. On weighing again, if the experiment be made at sea

level and at the temperature of freezing water, the increase of weight of the globe will be about an ounce and a quarter; this is therefore the weight of a cubic foot of air. A cubic foot of water weighs 62·4 lbs.

Fig. 142. How the weight of Air is determined.

A proof of atmosphere pressure is illustrated by Fig. 143. A thin tin vessel is taken and water boiled in it until it is full of steam. The neck is then tightly stoppered with a cork and

Fig. 143. Experiment to prove the existence of Atmospheric Pressure.

cold water poured on the outside; the result being that the can collapses. The reason is that the steam inside has been condensed and so the force which it exerts on the inside walls

has been diminished. And since the outside pressure exerted by the surrounding atmosphere remains practically the same during the experiment, the can collapses owing to its action. An analogy may be made by considering a half-a-dozen boys pushing on one side of a gate or door and the same number exerting an equal force in the opposite direction. The result is the gate remains stationary. But if the boys on one side cease to push, the gate quickly moves in the resultant direction of the forces remaining in action. The pressure of the atmosphere is 15 lbs. per square inch, so that an area of 10 sq. in. has a pressure of 150 lbs. upon it.

Air obeys the same law as other fluids in transmitting pressure equally in all directions.—A bit of paper lying on a table, or on the ground, in still air does not move, because the pressure tending to push it along in one direction is counteracted by that acting in the opposite direction. The pressure of the atmosphere is in fact exerted equally in all directions. It acts with the same intensity sideways or upwards as downwards. If this were not so, then a body suspended in air would move towards the point where the pressure was least. It is on account of this circumstance that we are able to move about in the air without any difficulty. Did it only act downwards we should be oppressed with the sense of a heavy weight wherever we were. In a similar manner the pressure is the same in all directions at a given depth in the ocean. The popular idea that the shell of a turtle is thick in order that the animal may walk along the bottom with comfort, in spite of the enormous pressure of the overlying water, is therefore erroneous.

Some effects depending on atmospheric pressure are as follows. Take a glass jar having a piece of sheet india-rubber stretched over one end of it, whilst the open end is put on the plate of an air-pump. When the air is pumped out of the interior of the jar, the india-rubber is forced inwards by the action of the outer atmospheric pressure and assumes the shape shown in Fig. 144. A converse experiment is to take two or three common air balloons, filled with air at the ordinary pressure, and

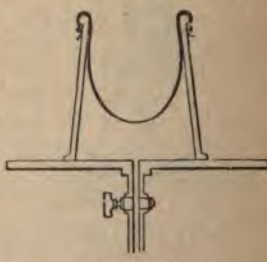


Fig. 144.
Illustration of Atmospheric Pressure.

place them under a bell-jar resting upon the plate of an air-pump. Before working the pump, the air in the balloons is exerting the same pressure on the inside of the elastic skin as the air surrounding them is exerting on the outside, and so nothing happens. But when the air is pumped out from the interior of the jar, that in the inside of the balloons expands in the direction of the lessened pressure and in so doing stretches out the bladders so that they burst or fill the jar.

Fig. 145 illustrates a useful instrument known as a pipette, which is used to adjust small quantities of liquid in making delicate measurements of mass or volume. If the lower end is placed in some water and a vacuum formed by sucking at the upper end, the pressure of the atmosphere forces liquid up the tube which can then be dropped out as desired. The action of a simple suction pump is precisely similar to this. A tube leads from the bottom of a cylinder into the water or other liquid which has to be raised. At the bottom of the cylinder there is a valve which can only open upwards, and fitting tightly in the cylinder is a piston also having in it a valve opening upwards. When the piston is drawn up from the bottom of the cylinder, it tends to leave a vacuum behind. The pressure of the atmosphere on the surface of the liquid outside, forces the liquid up the tube until it passes through the valve at the bottom of the cylinder. Then, at the next downstroke of the piston, the liquid imprisoned in the cylinder is forced through the valve in the piston, and is then lifted up to the level of the spout, out of which it flows when the piston is raised. It is found that water cannot be lifted higher than about 30 feet by means of a common suction pump. The reason is that the pressure of the atmosphere is only sufficient to balance a column of water having approximately this height. Similarly, mercury can only be raised about 29 inches by this means, for the weight of a column of mercury of this height is roughly equal to the pressure of the atmosphere.

Fig. 145.

A Pipette being used to drop small amounts of liquid into a test-tube.

An Air Pump has much the same action as the common pump. It is used to diminish the quantity of air in a vessel or closed chamber. The simplest kind of air-pump is shown in Fig. 146. When the piston is drawn outwards the pressure in the cylinder is diminished, and the air in the bell-jar on the plate of the pump expands, forces its way past the valve at the bottom of the cylinder, and fills both the cylinder and the jar. As the piston is pushed downwards the air in the cylinder passes through the valve in the piston to the outside. Another rise of the piston again diminishes the density, and therefore the pressure, of the air in the jar, and the process is continued until the air has been reduced to a sufficient degree of tenuity.

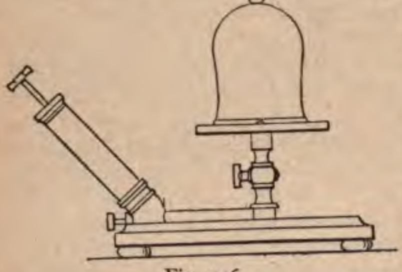


Fig. 146.
Simple form of an Air Pump, with a Bell-jar over its plate.

A Barometer is an instrument for measuring the pressure of the Atmosphere.—The principle on which its action depends will be understood from the following experiment. Take a glass tube about 3 feet long, closed at one end, open at the other—about $\frac{1}{4}$ inch in diameter is a convenient size—turn the tube up and fill it with mercury, put your thumb on the open end and place the tube upright in a cup or basin containing mercury (Fig. 147), take the thumb away; the mercury will fall a little in the tube and will then remain stationary at a height of about 30 inches. It is evident, therefore, that something must balance the weight of the mercury or it would fall down the tube, and this balancing agent is the pressure of our atmosphere. The atmosphere is pressing down on the surface of the mercury in the basin, and so keeping up the column of mercury in the tube. Conceive a tube having an area of a square inch to rise from the sea-shore to a point in the atmosphere where the air is so thin as practically to have no weight, and let an exactly similar tube contain 30 inches of mercury. The 30 inches of mercury would have the same weight as the long tube of air, and since a cubic inch of *mercury* weighs about half a pound, 30 cubic inches weigh 15 lbs..

that is to say, when there is a difference of level of 30 inches between the mercury in the tube and in the basin the atmosphere is pressing on all sides with a force equal to the weight of 15 lbs. on every square inch. In Fig. 148 a barometer such as is used

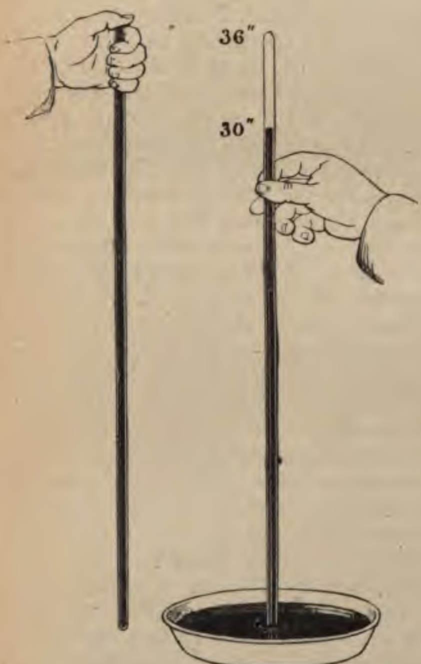


Fig. 147. Construction of a Barometer.

Fig. 148.
A Cistern Barometer with Thermometer attached.

for scientific work is shown; the scale attached is for finding how high the mercury stands, and a determination of the height at any time is called a *reading*. It is necessary that the readings should indicate the height of the top of the mercury column above the

level of the mercury in the cistern. This condition is obtained in the instrument figured by making the bottom of the cistern of chamois leather. By screwing the button at the bottom the height of mercury in the cistern can be adjusted so as just to touch the tip of a projecting point at the top. When the mercurial column stands above 30 inches the barometer is said to be high, when below 30 inches it is said to be low. Other liquids besides mercury are used for making barometers, but require a much longer tube to contain the column necessary to support the atmospheric pressure, on account of their being specifically lighter. Thus mercury is 13·6 times heavier, bulk for bulk, than water, hence a water barometer has to be at least $30 \times 13{\cdot}6$ inches, that is, 34 feet, long. If a hole were made in the top of any barometer tube, the air would get in and the liquid would fall until it was at the same level inside and outside the tube. From the description of the instrument it is evident that the part of the tube from the closed end to the top of the liquid in a barometer contains nothing but the vapour of the liquid employed. This vapour really exerts a pressure on the surface of the column of liquid, so that to be accurate we must say that the pressure of the atmosphere is balanced by the weight of the column of liquid, plus the pressure of the vapour. In the case of mercury, the amount of vapour pressure can be neglected, but when water barometers are used it must be taken into account.

The pressure of the atmosphere decreases as we ascend, and so the barometer column, which measures this pressure, falls somewhat; indeed, by observing the fall a traveller finds what height he is above sea level, and balloonists determine how high they have risen above the earth's surface. On account of this cause affecting the height of the column of mercury in a barometer, when accuracy is desired the height of the barometer station above sea-level must be known, so that the readings at any time can have a correction applied to them which will reduce them to the reading which would be found under the same atmospheric conditions if the instrument were situate at sea-level. The diminution is such that at three and a half miles the pressure is only half what is found at sea-level, that is, the barometer stands at 15 instead of 30 inches, at seven miles the reading is about seven inches, and at $10\frac{1}{2}$ miles only $\frac{1}{8}$ of the pressure at the surface is found. At this rate we find that at a height of 35 miles the pressure and density of the atmosphere is $\frac{1}{1000}$ of that at sea-level, and at 70 miles only $\frac{1}{1000000}$ the amount. In other words,

at a height of 70 miles 1,000,000 cubic feet of air would only weigh the same as one cubic foot taken at the earth's surface.

Cause of the Diminution of Atmospheric Pressure with increase of Altitude.—As we ascend in the air we leave a portion of the air behind us. There is not then so long a column to balance the column of mercury in the barometer, and therefore the mercury diminishes in height. That air is highly elastic and can be compressed is proved by the action of an ordinary pop-gun. It follows that since the earth is completely surrounded by an envelope of air the lower layers will be under greater pressure than the upper layers, for the same reason that when a pile of books lie upon a table the lowest book is under the greatest pressure. We see therefore that as we ascend the density diminishes, the same weight of air occupying a much larger volume. This is shown in Fig. 149, from which it will also be seen that air in rising must expand, and in falling must be compressed—two very important facts. Differences in the pressure of the atmosphere at sea-level are brought about by differences of temperature, and by an unusually small or large proportion of water-vapour.

Fig. 149.

A Stratum of Air at A A has to occupy the greater space B B when at the higher level, so it expands and is cooled by so doing.

The height of the atmosphere is not known with any certainty. The highest balloon ascent ever made was attained by Messrs. Glaisher and Coxwell in 1862, the height then reached being about 7 miles. Owing to the extreme rarity of the atmosphere, and the great cold, the observers became unconscious and could ascend no further. There is probably no fixed limit to the atmosphere. If there were no atmosphere, as soon as the sun sank beneath the horizon of a place darkness would occur. But we know that it is light some time after the sun has set and before he rises in the morning, and call these appearances twilight and dawn. These phenomena are produced by the air extending up to about 45 miles, but luminous meteors and shooting stars afford a means of proving the existence of air in a very rarefied form at a much greater height. A shooting star or meteor is a portion of matter drawn into the earth from outer space. In space it may be dark, but as it rushes into our atmosphere sufficient heat

is produced by friction with the air to melt it into a luminous streak. Determinations of the height at which shooting stars begin to be luminous prove the existence of extremely rarefied air so high as 200 miles. Whether there is still more attenuated air higher than this or not we do not know.

Preparation of Nitrogen.—At one time air was regarded as an elementary substance, but now it is known to consist essentially of a mixture of two gases, oxygen and nitrogen. If, therefore, we subtract the oxygen from a confined volume of air only nitrogen will be left. In order to do this place a jar, such as is shown in Fig. 150, over a piece of lighted phosphorus contained in a metallic or porcelain dish floating on water.

As the phosphorus burns, white clouds will be seen and the water will gradually rise in the jar, until the volume of air which it contains has been diminished by about one-fifth. The phosphorus will then cease to burn, although some of it may remain unconsumed. The white clouds will gradually dissolve in the water and give it an acid taste. It is evident that the gas in the jar has not the same chemical constitution as it had at the commencement of the experiment. The gas that has been used up by the burning of the phosphorus is called oxygen, and the white clouds formed by the combination of the two elements is called phosphorous oxide (P_2O_5). The colourless gas remaining in the jar is called nitrogen. It is not necessary, however, that the phosphorus be ignited, for if a stick of phosphorus is preserved at the ordinary temperature in a confined volume of air, a slow diminution of the weight of the air takes place. Another method of preparing nitrogen by the subtraction of the oxygen of the air is, to sprinkle some iron filings over the inside of the jar used in the above experiments, and allow the jar to stand inverted over water for a few days. The iron unites with the oxygen to form a compound chemically

Fig. 150.
The burning of Phosphorus in a jar of Air.

known as iron oxide (Fe_3O_4), and commonly known as rust. If sufficient filings be employed, all the oxygen in the jar will be used up to form rust, and nitrogen will remain behind.

Properties of Nitrogen.—In the experiments described above it was noted that nitrogen would not allow phosphorus to burn in it. This negative property of nitrogen can also be demonstrated by plunging a lighted taper in a jar of the gas, and observing that it is at once extinguished. It will also be seen that nitrogen does not kindle when a taper is introduced into it. All the properties of nitrogen are negative, or, in other words, nitrogen is characterised by an absence of properties. It has no taste, smell, or colour; it neither burns nor supports combustion, and an animal forced to breathe it would die in a few minutes. It is not, however, poisonous, as are such gases as carbonic oxide and carbon dioxide, but destroys life, by excluding air and occasioning suffocation, in precisely the same way that death is caused by drowning in water.

Proof of the Presence of Oxygen in Air.—We have demonstrated the presence of an inert gas called nitrogen in the air, and occupying about four-fifths its bulk, but have not yet indicated an experimental proof of the existence of oxygen. Now it can be shown that phosphorus, when burnt in air, increases in weight. Similarly, iron filings suspended by a magnet hanging on one scale of a balance increase in weight when heated. Again, when mercury is gently heated for some time red scales are formed on its surface, and the weight of the mercury increases. In each of these cases the increase of weight must be due to the taking up of some substance. By strongly heating the red scales just mentioned a gas is driven off which will re-kindle a glowing splinter of wood, and is known as oxygen. This gas, mixed with four times its volume of nitrogen, furnishes a mixture in which a taper burns, and which behaves, in all respects, like ordinary air. We may, therefore, say that the presence of oxygen in the air is proved by the fact that combustible bodies get converted into bodies containing oxygen, when burnt in it.

Exact Composition of Air.—Exact analyses of the proportional weights of oxygen and nitrogen in dry purified air show that 100 parts by weight has the composition :—

Oxygen ...	23	per cent.
Nitrogen ...	77	"
	100	

The proportion which the volume of oxygen bears to the volume of nitrogen in dry purified air is, as we have seen, about 1 to 5. More exactly the proportion is :—

Oxygen ...	20·8	per cent.
Nitrogen ...	79·2	„
	100·0	

But the proportion of oxygen to nitrogen is found to vary slightly. Air has been found to contain as much as 20·999 per cent. of oxygen, and as little as 20·913 per cent. This variation in composition is sufficient in itself to prove that air is a mechanical mixture, and not a definite chemical compound.

In addition to oxygen and nitrogen, air always contains minute proportions of other bodies, the most important of which are carbon dioxide (CO_2) and water vapour (H_2O).

The presence of carbon dioxide in the air can be proved by placing a little lime water in a saucer and leaving it for a few minutes. A white skim appears on the surface of the limewater, and gives a turbid appearance to it. This is because the lime (CaO) takes up carbon dioxide (CO_2) from the air, to form an insoluble film of calcium carbonate, or chalk ($CaCO_3$). The change is thus expressed :—

Lime.		Carbon dioxide.		Calcium Carbonate.
CaO.	$+$	CO_2.	$=$	$CaCO_3$.

Air contains, on the average, 0·04 per cent. of carbon dioxide. Sea air contains the same amount of the gas day and night; but on land there is much more at night than in the day, and on cloudy days than on bright sunny days.

The amount of water vapour in the air is very variable, and dependent upon circumstances which will be considered later on.

A gas called ammonia, and an active form of oxygen, called ozone, exists in air in varying quantities. The amount of these gases, cannot be calculated with any great degree of accuracy, even when large quantities of air are operated upon. The average proportion is about 1 part of ammonia and 2 parts of ozone to 1,000,000 volumes of air, that is to say, whether a pint, cubic foot, litre, or any other unit of capacity be employed, 1,000,000 pints, &c., of air contains, on the average, 1 pint, &c., of ammonia and 2 pints, &c., of ozone. The air of every large town contains certain foreign substances, due to various causes, such as the wear and tear of streets and buildings, the putrefaction of animal refuse, and the

burning of fires and lights. The average composition of 100 volumes of air, by volume, is shown in the following table :—

Oxygen	20·61	per cent.
Nitrogen	77·95	„
Carbon dioxide	0·04	„
Water vapour (about)	1·40	„
Ammonia	traces.	
Ozone	„	
	100·00	

Proof that air is not a chemical compound.—When bodies combine chemically, heat is developed and an alteration of bulk often occurs. Thus, when water is poured on to quicklime, the heat evolved is great enough to char and even to kindle wood. But when oxygen is mixed with nitrogen, no increase of temperature, or alteration of volume, or any obvious chemical change takes place. This indicates that the gases mix together and do not combine with each other. It has been shown that substances always combine together in proportions equal to their atomic weight, or simple multiples of them. If, therefore, nitrogen were combined with oxygen in air, the proportion of the two gases would be the same always. But this is not the case in reality. Neither are the numbers 77 and 23, which represent the proportional weights of nitrogen and oxygen in air, multiples of 14 and 16, which are the atomic weights of these two gases. A further proof is afforded by the fact that when water is shaken up with air, a portion of the air is dissolved. The residual air is found to contain a less proportion of oxygen than the original air, whilst the dissolved air contains a relatively greater proportion. This is because oxygen is slightly more soluble than nitrogen in water. The experiment proves at once that air is a mixture of gases, for a chemical compound of nitrogen and oxygen, as, for example, nitrous oxide (N_2O), would be more or less dissolved as a whole, and the composition of the dissolved gas would be exactly the same as that which was not dissolved.

Effects of animal and vegetable life upon the constitution of the atmosphere.—If air be expired from the lungs through clear lime-water, in a short time the liquid presents the turbid appearance which demonstrates the addition of carbon dioxide. But only a very faint turbidity is observed if air be drawn

into the lungs through lime-water. Again, if a candle be burnt in a clean glass bottle, the gas formed may be shown, by the lime-water test, to be carbon dioxide.

In each of these cases the oxygen of the air has combined with carbon to form carbon dioxide, thus:

$$\underset{\text{Carbon.}}{C} + \underset{\text{Oxygen.}}{O_2} = \underset{\text{Carbon Dioxide.}}{CO_2}$$

That water-vapour is expired from the lungs is very manifest on a frosty day, when it is condensed into steam as it leaves our mouths. The formation of water during ordinary combustion, can be proved by holding a bright glass over a burning candle and observing that it becomes dim with moisture. Here again the oxygen of the air is being used. The equation representing the change is:—

$$\underset{\text{Hydrogen.}}{2H_2} + \underset{\text{Oxygen.}}{O_2} = \underset{\text{Water.}}{2H_2O}$$

These reactions take place when all fires, lamps or gas jets are alight, hence there is a continual tendency to diminish the amount of oxygen in the air and to leave nitrogen, carbon dioxide and water vapour. But it is manifest that if the oxygen be subtracted from the air, combustion will be stopped. This is the reason that a candle placed under a jar soon goes out; it uses up the available oxygen. Man and all the animal creation also require oxygen to live; this oxygen is slowly consumed in their bodies, and carbon dioxide and water vapour are constantly being breathed out; so there must be another effect to balance these reactions, or all the oxygen in the air would in time be used up. The vegetable creation does this to a certain extent. It is found that, under the action of sunlight, plants and trees absorb carbon dioxide, use up the carbon it contains, and give out from their leaves pure oxygen, thus assisting in the balance of nature. The amount of carbon dioxide present in air therefore determines whether it is fit to breathe or not. The average amount is about 0·04 per cent., that is, about 4 parts in 10,000, and air containing more than 0·06 per cent. of the gas should not be breathed.

The source of atmospheric heat is almost entirely the sun. We receive an extremely small amount from the interior of the earth, from stars, meteors, and chemical combustion on the earth, but this is quite inappreciable when compared with that from the sun. This heat is imparted to the atmosphere in three ways, as follows: (1) Some of the sun's rays are absorbed in

passing through the atmosphere, and so the temperature of the atmosphere is raised. (2) The remaining rays reach the earth's surface and warm it, and the lower strata of the atmosphere get their temperature raised by contact. (3) The heat received by the earth is radiated to the atmosphere resting upon it. These 'dark' heat rays, or heat rays proceeding from a surface at a comparatively low temperature, have not the power of passing through the atmosphere like the luminous rays of the sun, so most of their energy is used up in heating the lower atmosphere. It is on this account that the temperature falls in ascending a mountain. Each of these effects will now be more fully considered.

The heat received from the sun during the day is not constant.—The fact that the sun's light, and therefore its heat, is more intense at noon than in the morning and evening is known to all. In the words of Sir John Herschel, 'The diurnal oscillation is a phenomenon which invariably makes its appearance in every part of the world *where the alternation of day and night exists.*' Within the Arctic circle, however, the diurnal oscillation dies out, or rather merges in the annual. The causes of

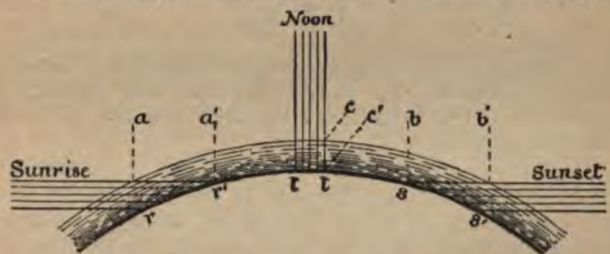


Fig. 151. Vertical and Oblique Solar Rays. At sunrise a bundle of the sun's rays is spread over the surface rr', after passing through a great thickness of atmosphere. At noon a bundle of the same number of rays is concentrated into the surface tt', after passing through the layers of atmosphere cc'.

this variation are as follows. In the morning and evening the sun's rays pass through greater thicknesses of atmosphere than at mid-day, and consequently a greater amount of their heat is absorbed, and less remains to warm the earth's surface.

Also, if we consider a cylindrical bundle of rays, it will be seen from Fig. 151 that their effect is greatest when they strike the earth's surface nearly or quite vertically, as at noon. At other times

of the day the same amount of heat is spread over a larger surface, and, therefore, a less amount is received over the same extent of surface.

The amount of heat received at different times of the year admits of a similar explanation. At the equator, the sun is nearly vertical at noon every day in the year, so there are no seasons and no annual range of temperature. In all other latitudes, however, the height of the sun above the horizon at noon is subject to an annual variation. At the summer solstice the sun's rays pass through the atmosphere in their most vertical direction, whilst at the winter solstice they traverse it most obliquely (Fig. 152). The proportion of heat absorbed by the

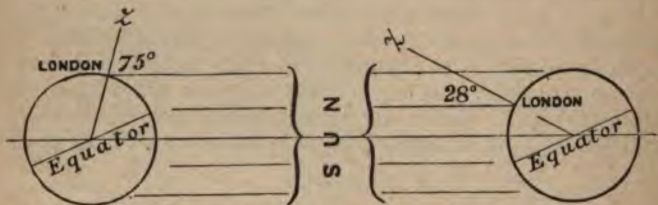


Fig. 152. Direction of solar rays at the summer and winter solstices to an observer in London. The noonday sun is 28° from the zenith in the former case, and 75° in the latter. Its altitude at midday is therefore 62° and 15° respectively.

atmosphere, and the spreading out of the solar beams over the earth's surface, is, therefore, least at the summer solstice and greatest at the winter solstice, for reasons similar to those stated in the preceding paragraph. On any day in the year, outside the tropics, the angle at which the sun's rays strike the earth's surface is more removed from the vertical as the latitude increases, the amount of heat received directly from the sun throughout the year decreases in passing from the equator to the poles.

The sun's rays not absorbed by the atmosphere have been estimated at about two-thirds of the total, the remaining third being absorbed on their journey. The first effect of the former portion is to heat the surface upon which they fall, and the rise of temperature produced depends upon the nature of the surface. The layers of atmosphere resting upon the warm surfa have their temperature raised by the contact, an

nicate their heat to others above them. The lowest layers are therefore the warmest. All bodies, luminous or non-luminous, send out rays whose energy may be transformed into heat. In the case of a body like the sun, some of the radiations are luminous, but there are many more rays which do not produce the sensation of light. These are termed obscure or 'dark' heat rays. On the other hand, a piece of iron below red-heat only sends out 'dark' rays. The earth can be regarded as a globe constantly radiating heat into space. It is not a luminous body, so the heat it radiates is 'dark.' During the day the earth is warmed by heat from the sun, and sends back to the atmosphere dark rays of heat. But rays of this character have not the penetrative power of the luminous rays of the sun, so they are mostly absorbed by the lower strata of the atmosphere, which in turn radiate their heat to the layers overlying them. There is thus an accumulation of heat near the earth's surface while the sun is shining upon it, for some of the sun's rays are trapped by the atmosphere and cannot re-traverse it. A similar effect is produced in a greenhouse, where the sun's rays penetrate the glass and raise the temperature of the interior, but the dark radiations from the interior cannot escape through the glass to the outside.

The absorbent power of the atmosphere is due to the presence of aqueous vapour.—Air containing little moisture has very little power of absorbing rays of heat, hence in such regions as the Sahara Desert and the central parts of Asia, Africa, and Australia, where the air is very dry, there is nothing to prevent the radiation of heat towards space, so at night, shortly after the sun's rays are withdrawn, intense cold prevails. Professor Tyndall has eloquently said: 'Aqueous vapour is a blanket more necessary to the vegetable life of England than clothing is to man. Remove for a single summer night the aqueous vapour from the air which overspreads this country, and every plant capable of being destroyed by a freezing temperature would perish. The warmth of our fields and gardens would pour itself unrequited into space, and the sun would rise upon an island held fast in the iron grip of frost.' The atmosphere thus behaves like a coloured roof of glass surrounding our globe. The proportion of heat lost by radiation decreases with an increase in the amount of moisture present in the air. On cloudy nights the loss is very slight, and even on clear nights the ever-present, invisible, aqueous vapour checks the excessive escape of terrestrial radiations which would *occur if it were absent.*

The horizontal distribution of temperature signifies the distribution according to latitude, and, from what has been previously said, it will be understood that a gradual diminution of temperature should occur in proceeding from the equator to the poles. (Fig. 153.) And if the earth were entirely covered with water, or consisted wholly of land, the temperature of any part would be determined by its latitude, and, therefore, all places having the same latitude would have the same temperature. The local causes which prevent this regular diminution will be alluded to later on. Meanwhile, the following table shows that a general decrease of temperature occurs as the latitude increases:—

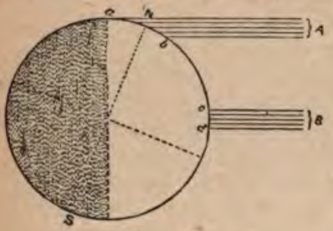


Fig. 153.

Variation of Temperature with Latitude. A and B are equal bundles of the sun's rays. The greatest effect is received at *c d*, and the least at *a b*.

	Latitude.	Mean Annual Temperature.
Abyssinia ...	13°	88° F.
Rio Janeiro ...	18	79
Cairo... ...	36	72
Naples ...	41	63
Marseilles ...	43	57
Paris	49	51
London ...	51	49
Moscow ...	56	40
Mageröe ...	71	34
Melville Island	78	25

The horizontal distribution of average yearly temperature is shown by the isothermal lines in Fig. 141, p. 284.

The vertical distribution of temperature signifies the distribution according to height above sea-level. As an approximate rule, the diminution is 1° F. for 300 feet of ascent. The following temperatures were observed by Messrs. Glaisher and Coxwell during their famous balloon ascent in 1862:—

At the earth's surface	59° F.	At the height of 3 miles	18° F.
,, height of 1 mile	41	,, ,, 4 ,,	—8
,, ,, 2 miles	32	,, ,, 5 ,,	—5

At the height of 7 miles —12° F.

This diminution is caused first by the fact that in ascending we pass into strata more removed from those heated by radiation from the ground at a general level; next, the air gets thinner and holds less moisture, so its absorbing power is decreased, and also its power to check radiation from the surface of the earth; and, finally, the ascending currents of air expand as they rise, and cold is produced by this cause.

QUESTIONS ON CHAPTER XVI.

1. Explain the chief reasons why mercury is the liquid usually employed in the construction of (*a*) barometers, (*b*) thermometers. (1889.)

2. How can the weight of air be determined? In what way is the pressure exercised by the atmosphere on the earth's surface, in consequence of its weight, stated? How is it that we are able to move about under the weight of the atmosphere? (1889.)

3. What difference will be observed in the reading of a barometer if we carry it from the sea-level to the top of a mountain three-and-a-half miles in height? Explain the cause of this difference? (1888.)

4. What are the two chief causes of difference in the pressure of the air at sea-level? (1888.)

5. What are the chemical elements present in pure air and pure water respectively? In what proportions are these elements present in each case? What is the difference between the condition in which the elements exist in water and in air respectively? (1887.)

CHAPTER XVII.

THE MOISTURE OF THE ATMOSPHERE.

Evaporation is the process by which a liquid is changed into a gas; and condensation, that by which a gas is transformed to a liquid.—We have used the term water-vapour and have stated that it is present in the atmosphere, although invisible. After a shower of rain the wet pavements begin to dry and the water disappears; if a saucer of water be left for a little time the liquid entirely disappears: clothes are put out to dry, that is, the water in them disappears. What has become of it? It is an unalterable law of nature that nothing can be lost, so the water must exist somewhere else, and we are led to conclude that it exists in the atmosphere as invisible vapour. That this is the case is easily proved. Every one has noticed moisture trickling down shop windows, and that an ice-cold piece of glass or metal when brought into a room becomes covered in a little time with a film of moisture, and it is evident that the moisture must have come from the air. Sulphuric acid, or oil of vitriol as it is commonly called, if left open to the air, gains considerably in weight and in bulk and gets proportionately weaker; this is because it has the property of absorbing water. All these examples prove that water exists in the air as an invisible vapour, and the process by which liquids are changed into the state of vapour is called *evaporation*, and the converse process, of vapour passing into the liquid state, is *condensation*. Liquids may be vaporised, that is, evaporated slowly as in the above examples, or quickly by boiling. In both cases, whether we leave a glass of water to disappear slowly or boil it away, the result is the same. Both evaporation and condensation are constantly going on all over the earth, hence the amount of vapour actually present is constantly changing. We have noted that the water disappears from the pavements because of evaporation; in a similar manner snow may be observed to disappear without a thaw, and a piece of ice, even during a hard frost, gradually loses weight owing to its evaporation. In fact, evaporation is going on at all times.

Evaporation takes place at the free surface of a liquid; when a liquid boils, however, vapour is being formed in the mass itself. We have noted that air may become saturated with water-vapour, and that the amount of such water that it can sustain in the form of vapour increases with the temperature. A cubic foot of air at 80° Fahrenheit will hold about twice as much water-vapour as a cubic foot at a temperature of 60°, hence, if air saturated at the higher temperature be cooled to the lower, half its vapour would be given up in the form of water—the water-vapour would be condensed. This fact explains why water is deposited upon cold substances brought into a warm room.

The amount of evaporation depends upon several circumstances. In the first place it depends upon the size of the exposed surface, and therefore takes place most extensively on the surface of the seas and oceans. Secondly, the amount of vapour formed depends upon temperature; the hotter the air the more vapour can it take up and hold, hence the quickest rate of evaporation occurs in the tropical regions, where the sun's heat is most felt, and, for a similar reason, a towel dries quickest when held to the fire. Thirdly, the amount of evaporation depends upon the quantity of the same vapour in the surrounding atmosphere, for it is manifest that if the atmosphere has dissolved as much water-vapour as it can hold, no more evaporation of water can go on. When this is the case, the air is said to be *saturated*, in the same sense that a sponge is said to be saturated when its pores are full of water. A corollary which follows from this circumstance is, that the amount of evaporation depends upon the renewal of the atmosphere, for such a renewal means merely the bringing up of unsaturated air; this explains why clothes dry quickest on windy days, when the air surrounding them is being constantly removed; if the air is still it soon becomes saturated with moisture and evaporation ceases.

The degree of saturation of the air can be measured by means of instruments called *hygrometers*. A convenient form of hygrometer, and the one commonly used, is shown in Fig. 154. It consists of two thermometers alike in every respect, except that one has its bulb covered with thin muslin, and around the bottom of the stem are twisted threads of cotton; these dip into a vessel of water about three inches below the bulb. The uncovered thermometer indicates the temperature of the air at any moment. The water from the vessel beneath the other instrument creeps up

the cotton threads by capillary action, and keeps moist the muslin round the bulb. Water is constantly evaporating from the muslin, and, as has been before pointed out, heat is necessary to change the liquid into vapour. This heat is subtracted from the mercury contained in the thermometer bulb, consequently the mercury in the stem sinks. And the amount of fall increases as the evaporation becomes more rapid. If the air contains very little moisture the evaporation goes on quickly; the bulb is therefore much cooled, and indicates a temperature several degrees lower than that shown by the uncovered thermometer. On the other hand, when the air is moist, very little evaporation occurs, and the two instruments, therefore, indicate very nearly the same temperature. To sum up then, the difference of the readings of the two thermometers gives us a means of estimating the relative amount of moisture in the air, and by comparing this with the quantity which would saturate the air we arrive at the 'degree of saturation' or 'hygrometric state' at the time of observation.

Fig. 154.
Wet and Dry Bulb Thermometers, for the estimation of the moisture in the air.

Dew is moisture deposited upon surfaces which have been cooled by radiation.—In spring and autumn the grass, leaves of plants and trees, stones, and other objects are often seen to be covered with drops of water which we call dew. Mr. Aitken has recently shown that most of the dew found upon plants is formed by the condensation of the water-vapour which is breathed out by them. Indeed, it would be impossible for the large amount of water often found upon leaves to have been contained in the atmosphere. The chilling of objects by radiation is primarily the cause of dew. In the day the earth is heated by the sun's rays; towards sunset, however, the amount of heat received by the earth from the sun is less than the amount it throws off or radiates. The surface of the earth and the *objects in contact* with it thus become cooled. When the cooling *by radiation* has gone far enough, the water-vapour rising from

the ground, and exhaled by plants, is condensed, and drops of water are deposited upon the chilled surface. The temperature at which condensation occurs is called the *dew point*. It is the temperature at which the vapour present is just sufficient to saturate the air. If the air is moist, the dew point is soon reached, but if it be dry a considerable fall of temperature will be necessary to cause the condensation of the aqueous vapour. Sometimes the air has to be cooled down below the freezing point of water before this precipitation point is reached; when this is the case, the moisture is deposited at once in the solid form, and *hoar frost or white rime* is formed instead of dew. It should be observed that hoar frost is not frozen dew, but water deposited in the solid state, and can therefore only be formed when the temperature is below freezing.

The causes which influence the production of dew are as follows:—Some bodies are better radiators of heat than others, they therefore cool quicker, and hence dew is first deposited on them. None is formed on polished metallic surfaces left out of doors because polished metals have a very low radiating power. Grass cools about twice as fast as ordinary garden soil, hence it becomes covered with dew much quicker than the soil. Another important cause influencing the production of dew is the state of the sky; on cloudy nights the heat radiated by the earth is radiated and reflected back by the clouds, so that the land cannot cool very much; on clear, cloudless nights, however, radiation can go on rapidly, and bodies on the earth's surface therefore become rapidly chilled. Winds also influence the amount of dew deposited, for, if there is much wind, the air does not remain long enough in contact with the cooling bodies on the earth to become cooled to a sufficient degree to deposit its water vapour.

Mists and Fogs.—A mist is often seen hanging over rivers and sheets of water in the evening. The reason of this is, that the sun's rays fall upon the water and land during the day, and raise their temperature; in the evening, however, when the sun has set, the land loses its heat quicker than the water, consequently it, and the air in contact with it, become cooled below the temperature of the water. A cold current is thus set up from the land to the water. But cold air cannot contain so much water vapour, bulk for bulk, as warm air, hence, when the warm water vapour over the lake or river is chilled by the colder air from the land coming in contact with it, the water vapour is deposited as *mist or fog*. A mist is sometimes looked upon as a rather more

condensed fog, that is, a fog passing into fine rain, hence a mist is said to feel somewhat wetter than a fog. But there is no hard and fast distinction between the two. Fogs are frequently caused by the mixing together of masses of air at different temperatures. Thus, the cause of the fogs which always hover over the banks of Newfoundland is, that the warm moist air over the Gulf Stream mixes with the air cooled by the cold Labrador current from the Arctic seas. Fogs are also produced when a current of warm moist air passes over a cool surface, such as an ice-floe or iceberg. It was proved by Mr. Aitken, in 1880, that the determining cause of the separation of moisture from an atmosphere saturated with aqueous vapour, and the consequent formation of fog, is the presence of particles of dust, around which condensation can take place. In the country the condensation of the comparatively pure aqueous vapour produces a white mist. But the numerous particles of dust and other foreign matters floating over the air of towns pollute the mist and convert it into a dark and sometimes almost black fog. By collecting and weighing the deposit formed on 20 square yards of glass in London during the last fortnight of February 1891, it was found that the amount represented 22 lbs. to the acre, or six tons to the square mile.

Clouds are elevated mists.—Mists may often be seen hanging over tops of hills and mountains; this is because the warm air strikes against the side and is forced upwards, so its temperature falls, and it can no longer hold so much water vapour as before. The only difference between a mist and a cloud is one of position—a mist rests on the ground; a cloud is a mist hanging in the air. One may see wreaths of cloud on mountain sides and summits, yet on standing in these clouds only masses of mist are visible. Clouds may therefore be produced by the mixture of two currents of air having different temperatures, by radiation from the mass of air to the cold sky, by the neighbourhood of cold surfaces—for example, mountain tops—or by the cooling effect of expansion when a mass of air ascends into a region of diminished pressure. Should the cooling effect still go on, the fine particles of water run together to form drops which fall to the earth as rain.

The heights of clouds vary considerably, the average in the temperate zones being about half a mile; it is manifest, however, *that the lightest clouds are the highest and the heaviest are the lowest.* If the cloud is at a great height above the earth when

the rain drops begin to fall, the drops will be large, because they unite together as they fall; if the cloud is low down, a fine mist falls, because the conditions have not been favourable to the formation of large drops. At a certain height above the surface of the earth—about three miles—the temperature is below the freezing point of water, hence any water vapour that gets into such regions is frozen and a fleecy cloud of fine ice needles is formed. The large halos that are sometimes seen around the sun and moon are caused by the action of these particles upon the light of our luminaries.

Clouds are classified according to their shape into three principal varieties, viz.: (1) The *Cirrus*, or mare's-tail cloud; (2) The *Stratus*, or ground fog; and (3) The *Cumulus*, or wool-pack cloud. (Fig. 155.) Cirrus clouds have a feathery appearance, and often occur as white patches on a clear sky just before a change of weather sets in. They are the highest clouds and most probably consist of minute ice crystals. Stratus clouds are the continuous horizontal layers, more or less uniform in thickness, which appear near the horizon during the morning and evening of fine days. They are the lowest of all clouds. Cumulus clouds are the common dome-shaped masses springing from a more or less horizontal base. They have much the same shape as the globular masses of steam which may be seen to issue from the funnel of a locomotive. By combinations of these three primary types we get the *cirro-stratus* or 'Noah's Ark' clouds, which is almost always a sign of rain; the *cirro-cumulus*, or 'mackerel sky'; the *cumulo-stratus*, and the *cumulo-cirro-stratus*, or *nimbus*, which is 'a cloud or system of clouds from which rain is falling.'

Rain is produced by the coming together of the water particles forming a cloud so as to form larger drops, which fall to the ground on account of their weight. When the particles of water-vapour in descending to the earth pass through a stratum of air containing little moisture, they are evaporated, and consequently do not fall as rain, and it is only when the atmosphere traversed is nearly saturated, and the temperature is above the freezing point of water, that a fall can occur. The chief cause of precipitation of the water-vapour is an upward movement of the air, by which it is carried to a height where the temperature is below the dew-point. The tendency of a layer of air to ascend and so expand may result from a temperature above the average at a given time and place, or from the presence of an unusual amount of aqueous vapour. These conditions often prevail over large

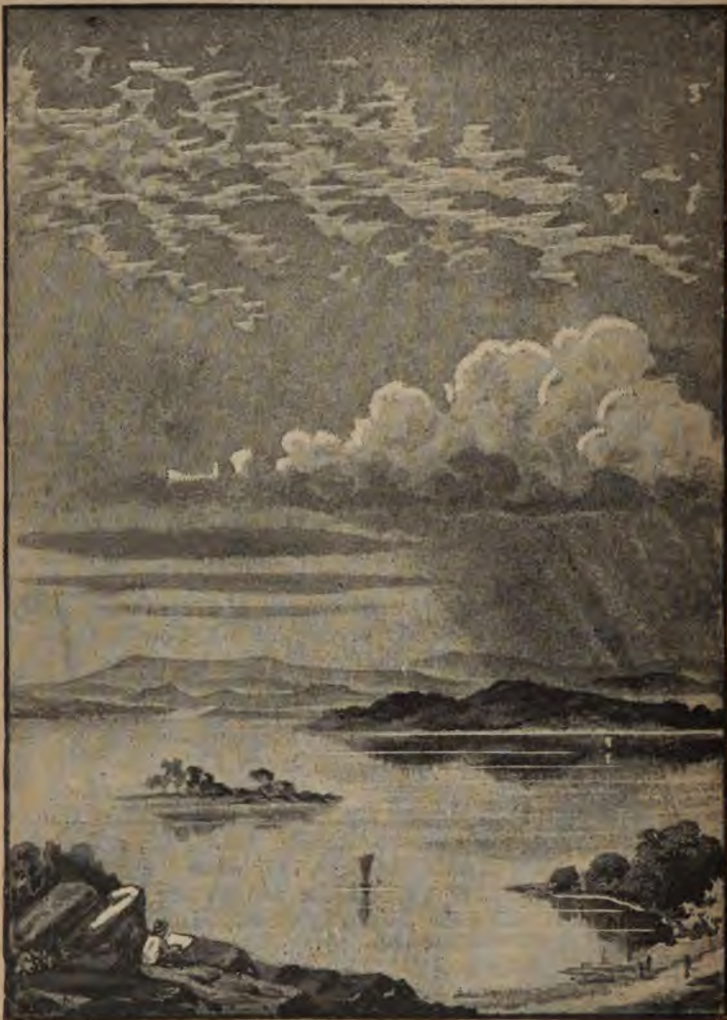


Fig. 155. Typical forms of Clouds.

areas. An upward movement is thus set up, and the surrounding air is drawn in to supply the place of the air that rises. And the air being cooled by elevation and expansion, its vapour condenses into drops. The condensation thus brought about liberates latent heat, and as the temperature of the air causing the current is increased, the tendency of the air at the surface to ascend is thereby increased. The drops may then fall to the earth as a shower of rain which, if the conditions are favourable, will continue for several hours. Of the atmospheric moisture which falls as rain, snow, hail, &c., about one-third has been estimated to return to the atmosphere again by evaporation, another third is absorbed by the land on which the fall occurs, and the remainder flows off the land at once into the rivers. This is only very approximately true, however, for we have shown that the rate of evaporation is dependent upon various circumstances. The amount of water which percolates into the soil is also very variable. In the Thames basin the months during which percolation of rain into the soil is usually most favoured by atmospheric influences are those included between October 1st and March 31st.

Rainfall is measured by means of a rain-gauge and is expressed as the thickness in inches of the fall if it were spread evenly over the surface of the land where it occurred. A rain-

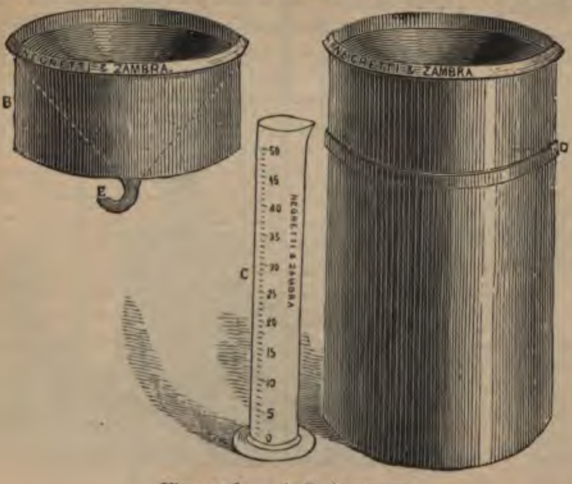


Fig. 156. A Rain-gauge.

gauge in its simplest form consists of a funnel to catch the rain and a bottle to receive it. The gauge used at most English meteorological stations has a receiving surface 8 inches in diameter, and therefore an area of about 44 square inches. The outer metal cylinder is sunk about 10 inches in the ground. To prevent loss by evaporation, the stem of the receiving funnel is bent upwards, as shown in Fig. 156. Beneath this tube, and inside the metal cylinder, is placed a metal pot to receive the rain water. The amount caught is measured at a certain hour (9.0 a.m.) every day by pouring the water from the inside pot into a graduated glass jar. The principle of the measurement will be understood from the following example. If the area of the funnel of a rain-gauge were as much as two square feet, and a gallon of water were collected, this is equivalent to a layer of water one inch thick spread over two square feet, and we therefore say the rainfall on a certain day was one inch. The weight of an inch of rain covering a square mile is about 60,000 tons, that is, an inch of rain gives about 100 tons of water per acre.

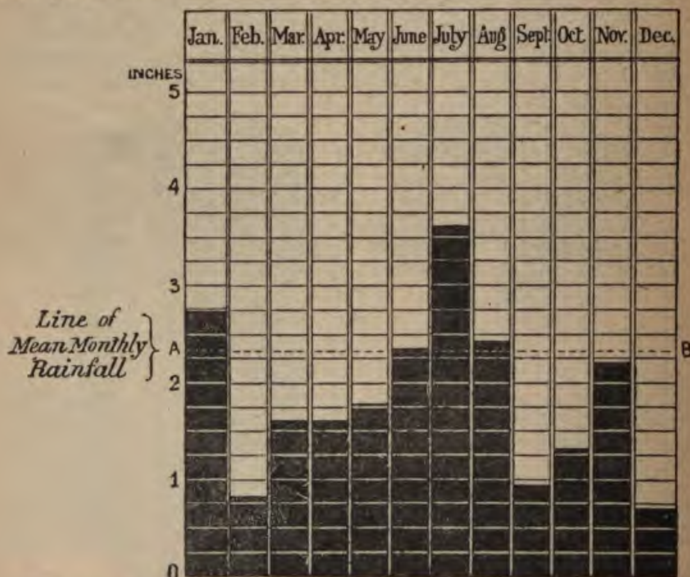


Fig. 157. Monthly Rainfall in the Thames drainage area during 1890.

The Mean Annual Rainfall of a place is the number of inches of rain that has fallen for a certain period divided by the number of years of observation.—The same causes that influence the formation of clouds must also influence the amount of rainfall, since rain only represents another stage in the condensation of water-vapour. The amount of evaporation that takes place is greatest at the equator, and therefore one would expect that there the average annual rainfall would also be the greatest, and, generally speaking, this is the case, the fall being greatest where the temperature is highest and therefore roughly decreasing as we recede from the equator and approach the poles. In nearly all parts of the globe, situated not far from the coast, the rainfall is approximately equal to the evaporation. The rainy days, however, are often fewest where the fall of rain is greatest. Fig. 157 shows graphically the monthly rainfall observed at twelve stations situate in the area drained by the Thames. The average annual rainfall over this basin during a period of ten years has been found to be 27·92 inches. The rainfall observed in 1890 at the same stations was 22·21 inches, that is, 20·4 per cent. below the average.

The conditions favourable for an abundant rainfall begin with the fact that the north-east and south-east trade winds on approaching the belt of calms near the equator, and being gradually deflected upwards, are cooled by expansion and by the cold of elevation, so that the aqueous vapour is condensed and the belt of calms becomes a belt of rain; indeed, the rainfall is so frequent and heavy, that this belt on the earth's surface is known as the *zone of constant precipitation.* A second cause for abundant rainfall is the influence of mountains, for when a strong wind strikes against a mountain it is forced up the side and elevated into a colder region, its vapour being precipitated by the cold due to elevation, and by the expansion due to diminished pressure. The influence of this cause will be apparent from the following comparison of the rainfall at stations close together, but differing in altitude.

Names of Stations.	Elevation in feet.	Mean Annual Rainfall.
Ben Nevis, Scotland......	4,407	141·76
Laggan, Scotland	821	49·30
Puy de Dome, France ...	4,806	60·82
" (at base)..	1,273	25·54
Carepipe, Mauritius	1,700	165·95
Beauvellon, "	240	60·48
St. Bernard, Switzerland .	9,413	63·36
Geneva, " .	1,335	29·53

A range of mountains running at right angles to the direction of the prevalent winds produces similar, but more marked, effects on the windward side. This is illustrated in every country where there are mountains, and is especially noticeable in Europe. An examination of any rainfall map makes it apparent that all the continents have wet coasts to the westward, and this is usually because the continents are more mountainous to the westward. A third condition favourable for rainfall is proximity to the ocean, especially when the prevalent wind comes from the ocean. It is on account of this and the preceding cause, that we have a higher rainfall on the West than on the East side of Great Britain, as shown in the following table.

West.	Rainfall in inches.	East.	Rainfall in inches.
Cornwall.........	38	Suffolk.........	$23\frac{1}{2}$
Gloucester	30	Middlesex ...	25
Lancaster	34	Nottingham...	25
Bute	$38\frac{1}{2}$	Fife	31
Perth	41	Orkney.........	24
Average	$36\frac{1}{2}$	Average	$25\frac{1}{2}$

Capes and headlands projecting considerably into the ocean generally have a rainfall greater than interior stations only a few miles inland. And finally, great and non-periodic depressions of the barometer are always accompanied by a considerable gale of rain, and the average tracks of these depressions are marked by an excess of rainfall.

Some conditions unfavourable to rainfall are as follows: Fresh winds blowing in a nearly uniform direction throughout the year, such as prevail within a portion of the system of trade winds, especially in mid-ocean. Some observations made on Ascension Island during two years showed that the direction of the wind was south-east, or very nearly so, during the time, and the annual rainfall 2·3 and 4·3 inches respectively. This condition of things prevails over the Atlantic Ocean within the region where the trade winds blow with considerable force and are seldom interrupted. A second condition unfavourable to rainfall is a position on the leeward side of a range of mountains running in a direction nearly at right angles to that of the prevalent wind. We have seen that a position on the windward side of such a *range causes an* abundant rainfall, but when the wind has passed

over the summit of the range it has lost a large part of its vapour, and when it descends on the leeward side it is warmed by coming under increased pressure and becomes a dry wind from which little or no rain can result.

A remarkable illustration of this fact is seen on the Malabar coast of Hindustan. On the ocean side of the range of mountains the mean annual rainfall is 250 inches, whilst on the eastern side of the range the air is very dry, and the amount of the mean annual rainfall is less than 25 inches. The dry state of Peru is owing to the fact that the high chain of the northern Andes takes out the last of the moisture which blows from the east across South America.

When there is a second range of mountains parallel to and within 200 or 300 miles of the first, the influence of this cause is much intensified, and the diminution is still more decided when a plain is surrounded by mountains, or nearly so. Salamanca is so situated, and the mean annual rainfall there is less than 10 inches.

Elevated plateaus have generally less rainfall than isolated peaks of an equal elevation; this is illustrated by the fact that the basin of the Great Salt Lake has an average elevation of 5,000 feet, and rainfall of 17 inches, and Leb, situated on the remarkable plateau of Tibet, has a mean annual rainfall of less than 3 inches. Another similar case is found in the table land (the Pumos) between two great chains of the Andes; and the fact that the average height of the Sahara is more than 1,500 feet may contribute in some degree to the smallness of the rainfall.

Another condition unfavourable to rainfall is the dryness of the atmosphere, for when the air is dry it has not so great a tendency to ascend, and by so doing to become cooled down to its dew-point. Under the head of dryness three special cases may be included, viz.: (1) remoteness from the ocean, measured in the direction from which the prevalent wind proceeds, (2) areas of high barometric pressure, and (3) high latitude. This last condition does not state that the average amount of rainfall regularly diminishes as we go northward like the average temperature, but if the mean annual rainfall be taken for every 10° of latitude, the important influence on the amount of rainfall is very decided, and is emphatically exhibited in high latitudes. The small number of observations of the fall of rain or snow during the various Arctic Expeditions bears out this principle.

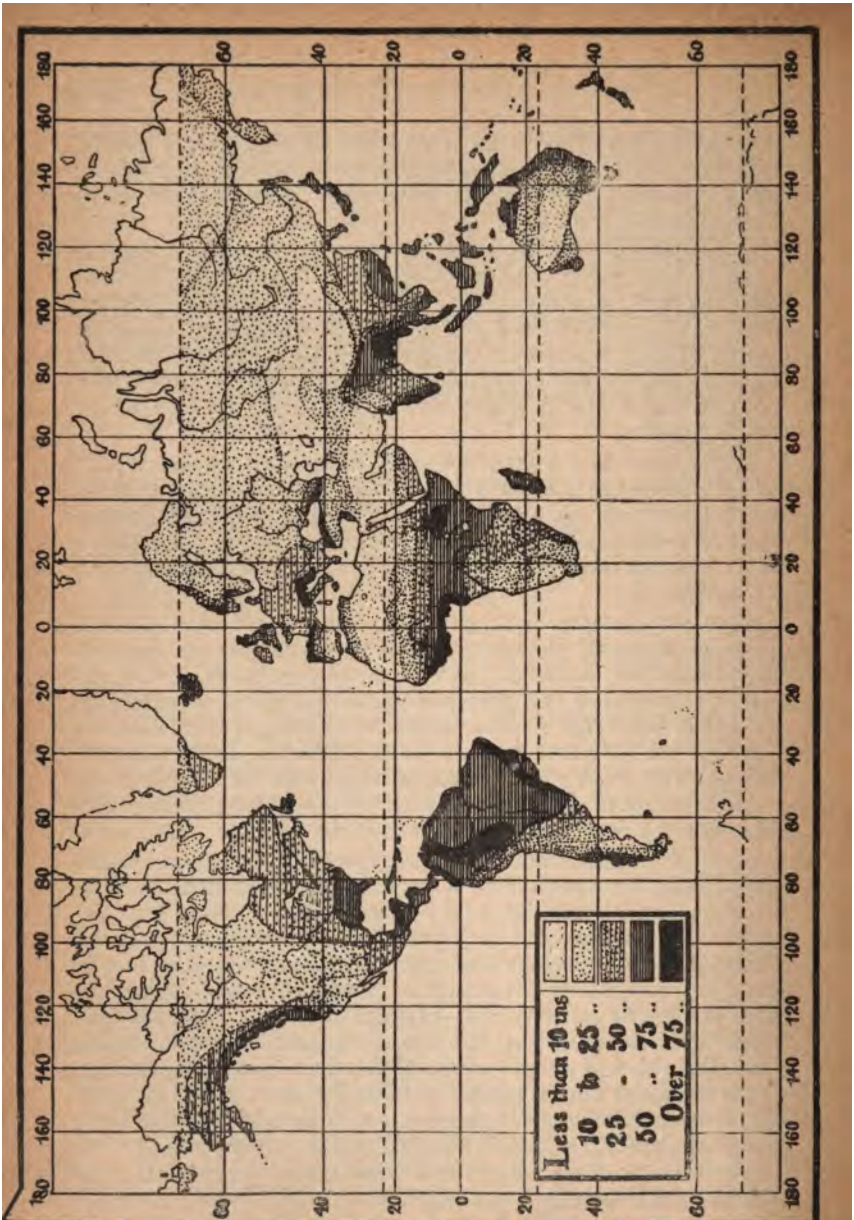


Fig. 158. *Distribution of* Rainfall, based upon the chart given by Prof. Loomis in 'Contributions to Meteorology.'

Regions of Great Rainfall.—Some of these regions have been already noted. Cherra Ponge is situated on the Khasi Hills, 200 miles north of the Bay of Bengal, and at an elevation of 4,455 feet. It has the remarkable mean annual rainfall of 475 inches. This is due to (1) the high temperature of the air, (2) great humidity, owing to its coming directly from the Indian Ocean, (3) the proximity of the mountain to the ocean, and (4) the abruptness with which the mountain rises from the lowlands in the south. The greatest known mean annual rainfall in Europe occurs at Seathwaite, Cumberland, the average of 24 years' observation being 143 inches. This remarkable precipitation is due to the influence of two neighbouring mountains, Skiddaw and Helvellyn.

Rainless Regions and the causes of their aridity.—Besides the districts noted as having very little rainfall, there are certain almost rainless regions whose aridity depends not only upon the general conditions we have laid down, but on other causes. (Fig. 158.) The Desert of Sahara is a well-known tract of this character. In it the rains are generally of short duration, and of small geographical extent. The cause of the small rainfall of the Sahara does not appear to be precisely the same in summer as in winter, and different explanations have been put forward to account for this. Prof. Loomis considered the two cases separately, and we cannot do better than quote his opinion:—'In winter the northern margin of the equatorial rain-belt retreats almost to the equator, so that with slight exceptions the whole of Africa, from the parallel of 30 deg. down almost to the equator, is well-nigh rainless. Throughout this whole region the distribution of atmospheric pressure, temperature and humidity, is such as to cause a prevalence of northerly winds. From lat. 30 deg. to the equator the average pressure diminishes somewhat over a quarter of an inch, which gives an average gradient of about 0·01 inch for each degree of latitude. The temperature increases by more than 30 deg., and the humidity of the air also increases. These causes are sufficient to determine a prevalent wind from the north, and all the observations we have from this region fully confirm this conclusion. These northerly winds in their progress towards the equator are continually advancing into a warmer region, that is, they are becoming drier, and this is a condition unfavourable to rainfall. . . . . . . In summer the distribution of temperature and pressure over Africa are very different from what they are in winter. In summer the highest

temperature is found near the parallel of 20 deg. N., and here the mean temperature is about 100 deg. Fahrenheit, or 20 deg. greater than it is on the equator. The result of this intense heat is that the air is expanded, it swells up and flows off to other parts of the globe, leaving a diminished pressure over the region of greatest heat. Thus in summer over Northern Africa, there is a permanent area of moderately low pressure, whose centre is near lat. 17 deg, N.. and here the mean pressure is about a quarter of an inch less than it is at the equator. This distribution of temperature and pressure determines the direction of the prevalent winds. In Northern Africa, down to near the parallel of 17 deg., northerly winds prevail, and they generally have an inclination to the north-east. Between the parallel of 17 deg. and the equator, southerly winds generally prevail. The rainfall is intimately connected with the direction of the prevalent wind. In Northern Africa, where northerly winds prevail, the atmosphere advances from a cooler to a warmer region, which is a condition unfavourable to rainfall. But this case is counteracted by a much more powerful influence. The great equatorial rain-belt, which is the result not of local causes but of causes which depend upon the general circulation of the atmosphere for the entire globe, advances in summer into the northern hemisphere, and the resulting rains sometimes extend northward to lat. 17 deg. Thus in summer the rains of Africa extend from the equator to near the parallel of 17 deg. N.; but north of this line the entire continent is well-nigh rainless. The result for the entire year is that there is an extensive region where the mean annual rainfall it less than 10 inches. The boundaries of this region are somewhat irregular, but the southern boundary is near the parallel of 17 deg., and the northern boundary is somewhat north of the parallel of 30 deg.'

The aridity of the Arabian Desert may be similarly explained. In winter, northerly winds prevail, and the general result is an almost entire absence of rain. In summer, southerly winds prevail to about lat. 20 deg. N., but north of this northerly winds prevail. The conditions are, therefore, like those of the Sahara, both in this respect and in the fact that the country is situated upon a plateau from 3,000 to 5,000 feet above sea level.

Similar conditions prevail throughout the region of small rainfall in Persia and Beluchistan, for this region has an elevation of from 4,000 to 6,000 feet.

Thibet owes its desert character to its position on the leeward side of the Himalayas, and its extreme elevation.

The Great Sandy Desert of Gobi is the result of three causes as far as rainfall is concerned, viz.—(1) considerable elevation; (2) its prevalent winds blow from a desert region; (3) the existence of a range of mountains in the south-east to take out the moisture of winds blowing from the Pacific Ocean.

The small rainfall in the vicinity of the Caspian and Aral Seas is due to some extent to position in the interior of a large continent. Northerly winds also prevail in the latter region at all seasons of the year, and these help to render it more arid than other parts of European Russia.

A region in the extreme north of Asia, and another in the northern part of North America, probably owe their small rainfall to remoteness from the ocean, measured in the direction of prevalent winds, and to their high latitude.

There is an area in Northern California and Arizona in which hardly any rain falls. This is because a prevalent wind blows from the north, and as it blows from a colder to a warmer region, its capacity for holding moisture is increased—a condition unfavourable to rainfall.

In summer southerly winds prevail in the region of the Great Salt Lake, and as they tend towards a region in which the air is excessively dry, little rainfall occurs. The principal desert in the southern hemisphere is in Australia. During the colder months of the year the winds blow from the interior of this continent. During the warmer months the interior of Australia is extremely hot; hence, although the prevalent winds are then towards the interior, their capacity for moisture is increased, and therefore very little rain falls.

The small rainfall of the Kalahari Desert in South Africa appears to be the result of conditions similar to those of Australia, and therefore admits of a similar explanation.

In general, during summer, the prevalent winds blow towards desert regions, and in winter the winds flow out of them. And as the majority of these regions are also surrounded more or less by high hills, a low rainfall is occasioned.

Snow.—When the temperature of a cloud is below freezing point, the aqueous vapour is solidified into minute crystals of ice. And, if the strata of air beneath are also below freezing point, and contain much moisture, the particles of ice become connected to form snow-flakes, which fall to the earth as snow. Snow-flakes

which have accumulated in calm air often exhibit symmetrical forms of great beauty, belonging to the hexagonal system of crystals. When the air is intensely cold the snow which falls is of a powdery character. In very dry weather small round pellets are produced, and during warmish weather any fall of snow which may occur is generally made up of large flakes produced by the accumulation of smaller ones.

Snow is never seen at places in the torrid zone, for though it were formed in the higher and colder regions of the atmosphere it would be melted before reaching the surface of the earth; hence it is never seen in places where the average temperature is much above freezing point.

The Snow-Line, or limit of perpetual snow, is the name given to the height above which the summer heat is unable to melt all the winter snow, and below which the summer heat is sufficient to do so. It is evident that snow may be formed at some height all over the globe, although its occurrence at sea level is confined to certain parts. At the equator, where the temperature is high, it is only seen on the loftiest mountains. Peaks of the Andes and other mountains have frequently a greater elevation than the snow-line, and therefore are perpetually covered with snow. At the poles the surface of the ground is similarly covered to sea-level. But this perpetual covering of a surface with snow means that more snow is formed than can be melted by the heat of the sun. Hence there is a certain height above sea level all over the globe where snow can perpetually exist, and the height will be greatest where the sun's heat is greatest, and least where the sun's heat is least. An imaginary line joining the heights above which occurs perpetual snow is called the *snow-line or limit of perpetual snow*. Below the line, the heat of the sun is sufficient to melt all the snow that falls. The following is the height of the snow-line at various places:—

	Latitude.	Height of Snow Line.
Quito	0°	16,000 feet.
South side of Himalayas ...	28 N.	16,000 ,,
North side of ,, ...	29 N.	20,000 ,,
Sierra Nevada	37 N.	11,000 ,,
North side of Alps	46 N.	8,000 ,,
South side of ,, ...	46 N.	9,000 ,,
North Cape	71 N.	2,000 ,,
Spitzbergen	78 N.	Near sea-level.

There is thus a gradual descent of the snow-line as the latitude increases. The height of the limit does not depend entirely upon latitude, however, but is affected by local circumstances. This will be seen from the two bracketed cases.

Sleet is snow that has been somewhat melted by passing through a warm stratum of air—a mixture of half-melted snow and rain.

Hail consists of hard pellets of ice or snow.—It may fall in hard or soft pellets and is known as hard or soft hail. The pellets may vary in size from a small pea to a pigeon's egg, large hailstones being formed by the freezing together of small hailstones during descent to the earth's surface. On cutting a hailstone into two and examining it under a microscope a speck of dust or some such matter is usually visible near the centre. Hailstones also present the appearance of being built up and not the appearance that would follow from the sudden freezing of drops of water (Fig. 159); hence the impression that hail is rain

Fig. 159. Hailstones.

frozen as it falls is entirely erroneous; but although this gradual formation is beyond doubt, no sufficient theory has been propounded to account for the fact that the hailstones remain suspended in the atmosphere.

Sometimes hailstones consist of soft white snow without any apparent nucleus, and at other times they are so hard as to require a heavy blow to break them. In the latter case the broken hailstones often present a stratified structure, with a centre of clear ice, concentric rings of solid and spongy ice, and an outer covering of snow.

QUESTIONS ON CHAPTER XVII.

1. What are snow-flakes, and how are they formed? (1887.)

2. Under what conditions is a country likely to have an abundant rainfall? (1887.)

3. What are the chief substances present in the atmosphere in addition to oxygen and nitrogen, and in what proportion do these additional substances occur? (1886.)

4. How is a raindrop formed? (1885.)

5. Give a drawing of a rain-gauge, and state the principle of its construction? (1883.)

6. How are snow and hail formed? (1882.)

7. What is meant by the rainfall of a place, and how is it measured? (1882.)

8. Explain the fact that no dew is found upon the ground after a cloudy or windy night? (1881.)

9. State the causes which may give rise to an excessive rainfall in a district, illustrating your remarks by examples? (1881.)

10. When water is left standing in a vessel out of doors it gradually disappears. State what becomes of the water, and under what conditions of the atmosphere it will disappear most rapidly? (1879.)

11. Describe some of the forms found in snowflakes, and explain their origin? (1879.)

12. What is the cause of the great cold which prevails in the Polar regions? (1883.)

13. Why is the heat so great in the equatorial regions of the globe? (1884.)

CHAPTER XVIII.

THE MOVEMENTS OF THE ATMOSPHERE AND GENERAL CONDITIONS OF CLIMATE.

CONSIDER our globe at rest, isolated in space and covered uniformly with water; it can be well understood that in such a case there would be no tendency for the water to move from one point to another. In the same way, if the earth were at rest and surrounded with an atmosphere of uniform density, and if the sun did not exist, there would be no movement of the air, and winds would be unknown; but we know that the air is subject to disturbance, and indeed seems never still. Light breezes are constantly moving the leaves of the trees, or heavy winds roughly shaking the trunks. What is the cause of the movement, and what are the laws that govern it, are questions to be answered in this chapter. In Chapter XVI. the barometer, an instrument by which the atmospheric pressure is measured, was described; and since it is differences of atmospheric pressure that regulate the motion of winds, by studying the readings of barometers at different times, and at various places, we may learn something about atmospheric motion.

Differences of atmospheric pressure are caused by the unequal heating of the air, or by its unequal humidity.—It may have been noticed that when describing how the weight of air is determined (p. 287), we said that the value given only held good when the temperature was that of freezing water. If the experiment had been made at the temperature of boiling water, the cubic foot of air would have been found to weigh about $\frac{9}{10}$ oz., hence hot air is lighter, bulk for bulk, than cold air. Again, moist air is lighter, bulk for bulk, than dry air. A cubic foot of dry air at a temperature of 50° F. weighs nearly 547 grains, whilst a cubic foot of water-vapour at the same temperature only weighs a little over 4 grains. The humidity or quantity of water-vapour that air can hold is different at different temperatures—the hotter the air the more vapour can it hold. Now, the more water-vapour the air at any place contains, the less is the atmospheric pressure at that place, and, therefore, the lower is the barometer.

Winds are caused by differences of atmospheric pressure, and, therefore, any circumstance that is the cause of a change of temperature of the air, or affects the amount of moisture it contains, causes a wind to be set up.

Land and Sea Breezes.—At the seaside during the day a breeze blows in from the water, and is called a *sea-breeze;* after sunset, however, the wind veers round and blows from the land to the sea—this is called a *land-breeze*. These breezes are well marked in or near the tropics, but are not so noticeable in our latitudes. We have shown that some substances take more heat than others to raise them to a given temperature, and therefore, other things being equal, these substances take longer to heat or to cool than others. Water takes more heat to raise its temperature one degree than the same weight of any substance, and is also a poor radiator of heat, hence water takes much longer to lose its heat than

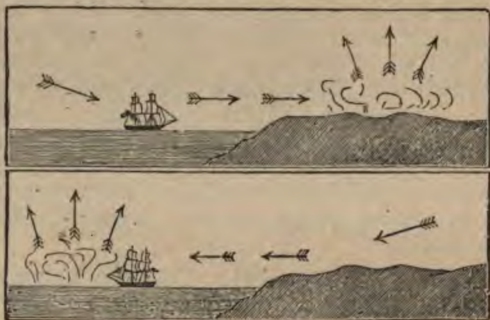


Fig. 160. Sea and Land Breezes.

anything else. When the sun is shining upon the earth during the day it is known by common experience that the land soon becomes hot; the water, however, does not become so warm, hence the air resting on the land in the day is warmer than that resting on the water and so a sea-breeze is set up; a slight current flows from the colder, and, therefore, denser air to the warmer and lighter. In the evening the sun's rays are withdrawn, the land loses its heat quicker than the water, and the air resting upon it becomes cooler than that resting on the water, so a land-breeze is set up, the current again flowing from the colder and heavier air to the warmer and lighter (Fig. 160), the tendency always being for the air to flow and keep in motion so long as a difference of temperature exists.

Measurement of the direction and pressure of Winds.—The direction of wind is indicated by an ordinary weathercock or other wind-vane. The apparatus should be fixed above the roofs of neighbouring houses or trees, and the cardinal points (N. S. E. and W.) should of course have their true, not the magnetic, direction. The other 'points of the compass' are described in Chapter XXI. It may be well to point out that winds are named according to the point from which they blow, differing in this respect from ocean currents, which are named according to the direction towards which they flow.

Fig. 161. An Anemometer, for the determination of the Velocity of Wind.

The force of the wind is measured by an instrument termed an *anemometer*. One form, due to Dr. Robinson, is shown in Fig. 161. The wind causes the four hemispherical cups to revolve, and their motion turns the vertical axis, which is in gear with a hand capable of moving round a graduated dial. The anemometer illustrated by the figure has two graduated circles. One circle indicates motions of the anemometer cups up to five miles, and the other circle from 5 to 505 miles. The velocity of the wind at any particular moment is found by observing the index before and after a certain interval of time, say five minutes, and then multiplying the amount of motion of the hand by twelve to find the velocity in miles per hour. Of course if an interval of only a minute

were taken the amount of motion would have to be multiplied by sixty in order to find the velocity of the wind in miles per hour. On account of friction and other circumstances the cups only travel at about one-third the rate of the wind, but this is allowed for in graduating the dials so that true readings can be obtained at once. When the velocity is known the pressure can be calculated. The following table of velocities of winds and the consequent pressures is taken from Scott's 'Meteorology':—

	Miles per hour.	Lbs. per sq. ft., approximately.
Calm	3	·08
Light Air	8	·6
Light Breeze	13	1·5
Gentle Breeze	18	2·9
Moderate Breeze	23	4·7
Fresh Breeze	28	6·9
Strong Breeze	34	10·2
Moderate Gale	40	14·2
Fresh Gale	48	20·3
Strong Gale	56	27·8
Whole Gale	65	37·5
Storm	75	49·9
Hurricane	90	71·8

In some cases the gusts of wind have a velocity of 120 miles an hour, but rarely more.

The conditions which respectively cause a barometer to stand high or low, under ordinary circumstances are thus stated by Scott, after Prof. Mohn.

A barometer stands high :—

(1.) When the air is very cold, for then the lower strata are denser and more contracted than when it is warm.

(2.) When the air is dry, for then it is denser than when it is moist.

(3.) When in any way an upper current sets in towards a given area, for this compresses the strata beneath.

Conversely a barometer stands low :—

(1.) When the lower strata are heated, causing the surfaces of equal pressure to rise, and the upper layers to slide off, for by this means the mass of air pressing on each unit of area below is reduced.

(2.) When the air is damp, for as the density of aqueous vapour at the temperature of 60° F., and pressure of 30 inches, is 0·622, air being 1, the mixture is lighter the more vapour it contains, and consequently damp air does not press so heavily as dry on the unit of area below.

(3.) When the air from any cause has an upward movement, for this of course acts in the same manner as (1).

Extending this reasoning to the case of the earth taken as a whole, we have the fact that the air is hottest over the torrid zone; ascending currents are therefore set up, and other currents rush along the earth's surface to take the place of the ascending air. Where the ascending currents occur the barometer will read lower than at higher latitudes, and, as a matter of fact, at the equator the average barometric height at the level of the sea during our winter is 29·88 inches, whereas in latitude about 40° N. it has been found to be 30·20 inches.

The Trade Winds.—It is evident from the foregoing paragraph that in the northern and in the southern hemisphere there is a constant tendency for two currents to flow from the direction of the poles along the earth's surface to the equator, and if the earth were at rest there would always be a north wind in the northern hemisphere, and a south wind in the southern hemisphere. But the earth is in rotation, the air at the poles has no motion of rotation, whilst the air at the equator is whirling round with the earth at the rate of upwards of 1,000 miles an hour—hence as the current flows from the poles to the equator it is constantly dropping behind, and instead of a wind blowing direct from the north pole we get a wind from the north-east, whilst in the southern hemisphere the wind blows from the south-east. These winds are constant and are called *north-east and south-east trade-winds*, because the early navigators depended upon them for commercial purposes. The north-east trades are chiefly felt between latitudes 6° N. and 35° N., and the south-east trades between latitudes 6° S. to 30° S.

The Anti-Trade Winds.—Besides the cold lower current flowing from high latitudes to the equator there is the upper warm current flowing from the equator to high latitudes. These return currents are gradually cooled in their journey poleward, and observations show that they reach the surface in about the thirtieth parallel of latitude. Here again, if only the change of temperature and therefore difference of pressure gave direction to the

return currents, they would flow due north and due south; but we have a combination of motions, the air has a higher velocity at the equator than in higher latitudes, consequently the currents flowing poleward are constantly getting ahead, and, since the earth rotates from west to east, they flow from the equator in a south-east direction, that is, from the south-west in our hemisphere, and form north-west winds in the southern hemisphere. Such winds are called the '*Anti-trades.*' In our hemisphere their effect is not striking because of the influence of the land, which causes

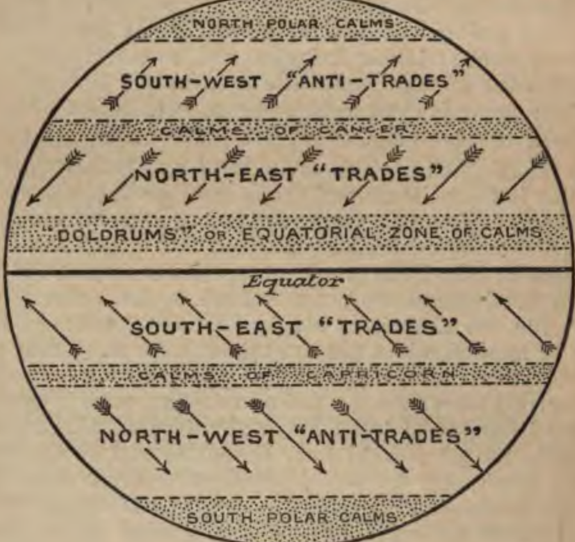


Fig. 162. Constant Winds and Calms.

irregular motion of the currents. In the southern hemisphere, however, where there is little land to get heated and cause local currents, the anti-trades blow with considerable constancy and force; and between latitude 40° and 50° in the Pacific and South Indian Oceans these winds are known as the *Brave West Winds,* and the latitudes in which they blow as the '*Roaring Forties.*'

The region of the south-west anti-trades extends from 35° N. *to 65° N.,* and of the north-west anti-trades from 30° S. to 65° S.

It is well known that the prevalent wind in Britain and the west of Europe is south-west, and the foregoing furnishes the reason for this. In towns where such winds are prevalent the 'west end' is always the best end, and the reason is obviously because they reach that end fresh and uncontaminated with the dirt and disease that are suspended over the towns, and blow these impurities to the east end. The general direction of the trade and anti-trade winds described is shown in Fig. 162.

Equatorial Belt of Calm.—It was pointed out in a previous chapter that the sun is only directly over the equator twice a year, that it journeys north and reaches the tropic of Cancer in July, then turns south and reaches the tropic of Capricorn in January, hence the trade winds do not constantly blow to and from the equator but to or from some zone north or south of it according to the position of the sun.

The irregular conformation of the land surface of the earth affects considerably the constancy of the trade and anti-trade winds. In January the belt of heated air lies nearly along the equator with little but sea under it, the consequence being that the trade winds are then more distinctly felt than when the sun is further north of the equator and the belt of heated air extends over Asia and the northern part of Africa. In the Atlantic and Pacific Oceans, where there is little land in the track of the winds, they are most regular. In the Indian Ocean the mass of land north of the equator and forming the continent of Asia prevents the north-east trade wind from blowing at all, and the south-east trade wind alone is constant.

We thus see that a circulation of air is continually going on, and it is manifest that where the north-east and the south-east winds meet they will neutralise each other—we shall have a belt of calms. Such a belt, about five degrees in breadth and characterised by low atmospheric pressure, runs nearly parallel to the equator, and is called the '*Doldrums*,' or the zone of calms; within it the heat is suffocating and sometimes intense calm prevails, at other times heavy rains and violent thunderstorms occur. If the earth were uniformly covered with water the belt of calms would always lie directly under the sun because that would be the line of greatest heat; the greater amount of land in the northern hemisphere, however, causes the line of greatest heat (the thermal equator) to lie north of the geographical equator, and therefore the belt of calms also. In the Atlantic Ocean the belt of calms lies entirely to the north, but as the sun

journeys north and south of the equator the belt moves with it; near the end of our summer it reaches its most northerly limit in eleven degrees north latitude, and towards the end of our winter its lower limit, in one degree north latitude, is reached.

Calms of Cancer and Capricorn are other similar belts caused by the crossing of the polar currents, forming the trade winds, and the return currents or anti-trades. Unlike the equatorial belt of calms, however, the calms of Cancer and Capricorn are characterised by high atmospheric pressure and generally bright weather. The former prevails in about lat. 35° N., and the latter in about 30° S. The trade and anti-trade winds are called constant winds, but the currents that prevail in the belts of calm are variable.

Monsoons are periodic winds which blow at definite periods and in certain directions.—They are caused by the unequal temperature of land and water at different seasons of the year or times of the day.

Some winds have a marked seasonal character, and it is to these we would now direct attention. Such winds are called *Monsoons*, which is the Malay signification for a season of the year. They are most perfectly developed in the Indian Ocean, where, as we have before noted, no north-east trade wind blows. During winter in India, that is, from November to April, the north-east monsoon prevails. The sun is then south of the equator—the temperature of South Africa is thus higher than that of Asia—the ascending currents cause the barometer to fall and currents of air blow along the earth from Asia to South Africa. They leave Asia as dry winds; as they cross the ocean, however, some moisture is taken up to be deposited on the south-east coast of Africa. The summer wind in India blows from May to October and is a south-west wind, which, it will be observed, has an exactly opposite direction to the course of the trade-winds. The sun is then north of the equator and Central Asia gets very hot, the result being that air colder than that lying on the plains of Asia is forced towards the centre of rarefaction. This cold air comes from the Indian Ocean and carries moisture, which is deposited in India and the east of Asia; indeed, the rainfall is so excessive during the summer monsoon in some regions that it is called the wet monsoon. On the coast of China the winter wind is a north-west monsoon, and the summer wind a south-east monsoon; the latter is looked forward to by the Chinese

farmer to water his land, and both are utilised by navigators of the Indian Ocean and China Sea in the same way as the trade winds.

Weak monsoons also blow in North America and even in Europe; they have the same cause, viz., the alteration in the temperature of these continents according to the position of the sun. As summer occurs the land and the air overlying it gets hotter than the surrounding water, consequently winds blow towards the centres of these continents from all directions, and the direction of the monsoon or periodic wind will depend upon the geographical position of any place in its track; in the winter, however, the land gets cool, air rushes out from the centre, and dry winds having a reversed direction prevail. The winds blow in upon all desert regions in the summer and flow out from them in the winter in both the northern and the southern hemisphere.

Some winds have local names, thus, the *Mistral* is a wind that blows over Southern France. It comes from the high land of Central and Eastern France, and therefore is a cold wind, generally accompanied by torrents of rain. In Africa and Arabia the *Simoom* occurs—a dry, hot, and suffocating wind, rushing across deserts and whirling up clouds of sand that bury whole caravans. The *Harmattan* is the name given to a similar wind that blows at certain times of the year from the heated Sahara to the coast of Guinea. The *Sirocco* is a similar hot wind, containing a great deal of moisture taken from the Mediterranean. It blows in a south-east direction towards Sicily and Italy, and causes extreme languor. In Spain it is called the *Solano*, and sometimes contains fine dust, carried across the narrow part of the Mediterranean from the deserts of Africa.

Isobars are lines connecting places where the barometric pressure is the same.—They may connect places having the same mean annual barometric height (the readings being reduced to sea level and a temperatue of 0° C.), or separate sets of lines may be drawn for each month showing where the pressure is the same, or one particular time may be chosen when all the barometer readings shall be taken at all meteorological stations. Thus, every morning observers at all the principal towns in England and on the continent telegraph the height of their barometer and the direction of the wind to a central office in London. A map is then taken and the isobars are drawn upon it for barometric readings of 30 inches, 29·9

inches, 29·8 inches, and so on, each line representing a reading differing by $\frac{1}{10}$ of an inch from the next. What these lines teach will be considered later.

Cyclones are variable or occasional winds blowing in more or less spiral curves.—The motion of cyclones on a small scale may often be seen on a dusty road. A whirling movement is set up and travels as a whole down the road, carrying clouds of dust with it. Similar movements of air on a vast scale are called *cyclones*, and all storms are of this character. If a cyclone in the northern hemisphere could be viewed from above the atmosphere, the whirl would be in the opposite direction to the hands of a watch; a cyclone in the southern hemisphere whirls in the same direction as watch hands (Fig. 163). In addition to this cyclonic movement the whole body of air moves, so that when a storm passes over a country first the wind blows furiously in one direction, then there is a short lull as the centre of the storm passes, and then the wind blows from an opposite direction. There is a gradual lowering of the barometer from just outside a storm area to its centre, and if it is found that there is a difference of one or two inches in the barometric heights, say at Paris and Bristol, a heavy gale may be expected—the greater the difference of atmospheric pressure or the steeper the 'barometric gradient,' the more violent will be the wind.

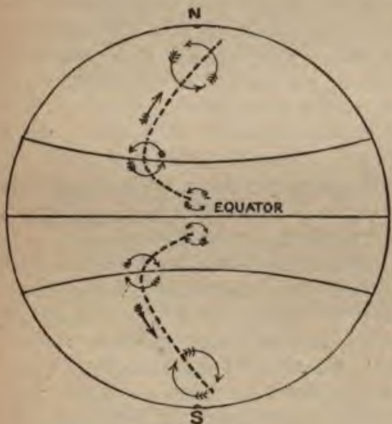


Fig. 163.
Movements of Cyclones in the North and South Hemispheres. The routes of cyclones are found to be roughly parabolic, as indicated by the dotted lines.

Weather Forecasts.—From the observations made at 8 a.m. every day in meteorological stations, isobaric curves are drawn, at the Central Office, on a map of Europe, round a centre where

the lowest reading has been taken. The curves may embrace an area thirty miles in diameter or a thousand miles, but the whole cyclone can thus be mapped out, and the direction of its movement being known, storm warnings are sent to places in its track. Now, there is a connection between the direction of the wind and atmospheric pressure, and it is expressed in what is known as *Buys-Ballot's law*, which may be stated thus:—'If you stand with your back to the wind in the northern hemisphere the barometer will be lower on your left hand than on your right. If you stand with your back to the wind in the southern hemisphere, the barometer will be lower on your right hand than on your left.' Hence, if the direction of the wind be observed, the distribution of atmospheric pressure may be deduced, or conversely, if the distribution of atmospheric pressure be known, the direction of the wind may be found, and it is by the utilisation of this law that storm warnings are rendered possible. The average rate of movement of a storm is from fifteen to thirty miles an hour; the whirl of the air that forms the wind, however, may have a much greater velocity.

The direction in which a cyclone travels is generally that of the prevailing wind. Thus a cyclone from the tropics moves in a westward direction towards the pole. In Europe, where the prevailing wind is westerly, storms generally come from the westward, so that they pass over France, Portugal, and Great Britain, and often lose their fury in Russia. It is rarely that a storm reaches the east coast of England without warning having been received.

Local Names of Cyclones.—It is easy to see that if water be in the track of a whirling mass of air a *water-spout* may be formed and made to move with it; if dust be in the track of the spiral, a simoon or dust spout may be the result. Various names have been given to cyclonic movements of the air in different localities. In the West Indies they are known as *hurricanes*, and in the China Seas and the Bay of Bengal, *typhoons*. What is known as a *tornado* is merely a whirlwind or cyclone having a small area. The violence of these whirlwinds is well known, and the track of one, although rarely more than a quarter of a mile wide, is like that of an advancing army—a path of destruction and devastation. One half of a house may be cut down and the other half remain uninjured, whilst heavy carts and trees are transported some distance by the movement of the whirling

spiral of air. A tornado does not last long, however, but exhausts itself after passing over about twenty or thirty miles.

Torrents of rain are usually associated with storms. The reason for this is, that as the air is whirled upwards it must expand, by expansion it becomes cooled, water-vapour is thus condensed and rain follows.

Characteristics of Cyclones and Anti-Cyclones.—Cyclones are characterised by (1) low barometric pressure, (2) the winds blowing approximately towards the centre, (3) the direction of the whirl being in the opposite direction to the hands of a watch in the northern hemisphere, and in the same direction in the southern hemisphere, (4) wet weather.

An anti-cyclone is an area of high barometric pressure, the centre showing the highest barometer reading. The lower air in a cyclone is made to rise and flow in a spiral course into the central depression; in an anti-cyclone the state of things is reversed, air flows out from the centre of highest pressure, and is caused to descend as it does so. The weather that accompanies an anti-cyclone is very different from that accompanying a cyclone. As the air in an anti-cyclone is forced to descend it becomes compressed and gets heated; it could thus take up much more moisture and hence always comes to us as a dry air; the sky is also generally free from clouds, although fog often occurs at the centre of the system. The memorable winter of 1890-91 furnishes an example of anti-cyclonic weather.

The motion of the wind in an anti-cyclone in the northern hemisphere is in the direction of the hands of a watch, being contrary to the motion in a cyclone; it is also generally more or less stationary, and does not move rapidly from west to east as a cyclone does in our latitudes.

Weather Charts.—Many of the daily papers now include charts in their columns, showing the height of the barometer on the morning of issue and giving other meteorological information. Fig. 164 shows the weather chart that appeared in the *Daily Chronicle* on December 8th, 1891. On this chart is indicated the height of the barometer on the morning of the date of issue, and the readings observed on the mornings of the three preceding days. The other indications are explained below the chart, and the remarks need no further omment.

Fig. 164. *Daily Chronicle* Weather Chart, December 8th, 1891.

EXPLANATION.

The thick line shows the variation in the height of the barometer during the past four days. The thin line shows the shade temperature for the same interval, and also the maximum and minimum readings for the day.

REMARKS.

8.30 P.M.

The depression which was advancing from the Atlantic to our south-west coasts on Tuesday has proved to be of great depth, and has caused gales over all parts of our islands, from between south and west in the Channel and the south of England, from south-west and south-east over the east of Great Britain, from the eastward in the north, and from north-west in the western parts of the kingdom. Over the channel the gale has been of great severity. At eight o'clock this morning the centre of the system lay over Wales, and during the day it has continued its north-easterly course across the northern parts of England. The disturbance was accompanied by heavy falls of rain generally, the amounts measured at many of our southern and south-western stations exceeding an inch. At six p.m. to-day pressure was highest, about 29·8 in., both over the Gulf of Bothnia and the Spanish Peninsula; lowest, about 28·3 in., a little to the east of the Firth of Forth. The barometer was falling quickly in the north and north-east, rising in the west and south, rapidly over the south of England. Gradients were still steep, especially over England and the North Sea. Temperature was highest, 49 deg., at Brest, Jersey, and Aberdeen; lowest, 41 deg. to 44 deg., over Ireland, 43 deg. in the Shetlands, 44 deg. at Shields and in London, and 45 deg. at York and Yarmouth. Wind was blowing a fresh to whole gale from west or west-north-west over England, and a strong south-easterly gale over the north and east of Scotland, Denmark, and the south of Norway. At Valentia Island it had backed somewhat since two p.m. Weather was dull and rainy in nearly all places, with squalls of hail at some of the Irish stations. In London and at Hurst Castle, however, the rain had ceased, and the sky was clearing. The amount of rainfall reported at Brixton since eight a.m. was 0·66 in., making a total fall of 1·14 in. during the past twenty-four hours. Sea was exceedingly high at Aberdeen, and high or rough on all parts of our coasts. The disturbance will probably continue to move away north-eastwards, and the

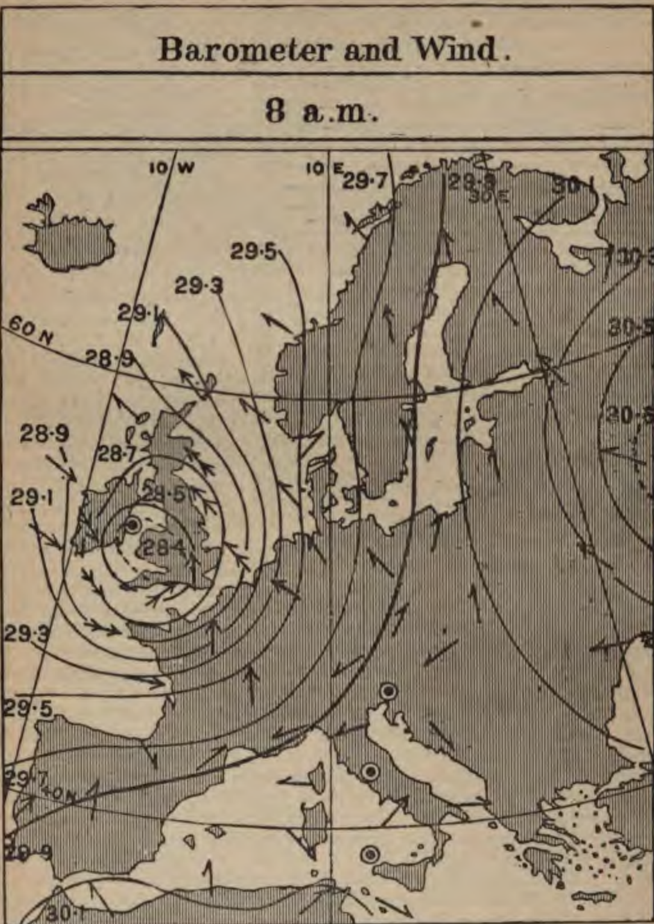


Fig. 165.

Diagrams to Illustrate the Severe Gale of Wednesday,

The barometer is expressed by isobars, the pressure corresponding to each line *are drawn flying* with the wind. ⊙ = a calm; —т = a light or

Fig. 166.

November 11, 1891 (by permission of the Meteorological Office).

being given in inches and tenths. The winds are shown by arrows which moderate wind ; ⟶ = a fresh or strong breeze ; ⟶ = a gale.

gales over our islands will gradually subside, with improving weather. The backing wind at Valentia Island, however, seems to show that secondary systems will shortly appear over the kingdom.

The cyclone of November 11, 1891, was one of the most severe that has occurred in England for many years, and a short account of the barometrical disturbances it caused should be of interest in this connection.

Mr. Charles Harding in an article that appeared in *Nature* on December 24th ably brought together some facts relative to the severe gale of November 11th. Figs. 165 and 166 are copies of a weather report issued from the Meteorological Office. They show the isobars prevailing over Europe at 8 a.m. and 6 p.m., and the direction and velocity of the wind, and illustrate the following remarks from Mr. Harding's paper.

'The conditions on the morning of the 11th are pictured in the diagram for 8 o'clock, obtained from the weekly weather report of the Meteorological Office, and from this it will be seen that the storm area was central over Pembrokeshire, the lowest reading being 28·36 inches at St. Ann's Head, whilst the mercury was below 29 inches over the entire area of the British Islands, and gales were blowing in most parts of the country. The cyclonic circulation of the winds was complete in our islands, the direction being northerly in Ireland, westerly and south-westerly over the Channel and the south of England, southerly on our east coasts, and easterly in Scotland and the northern portion of the Kingdom. The barometer gradients were very steep in the English Channel, as well as in the south-western and south-eastern districts; and at Scilly force 11 of Beaufort's notation was reported from the north-west. At many of the English stations the fall of the barometer since six o'clock the preceding evening exceeded 0·9 inch, and at Hurst Castle it amounted to an inch, whilst in several places in the south and west the rainfall exceeded an inch in the preceding 24 hours. The gale continued to rage during the day, and at two o'clock in the afternoon the force of the wind at Dungeness was reported as 12 of Beaufort's notation, which is the extreme limit of the scale, and is equivalent to a hurricane; the lowest barometer reported to the Meteorological Office at this time being 28·34 inches at Shields. At six o'clock on the 11th the central area of the storm had passed to the eastward of our coasts, as shown by the diagram for that hour, the core or heart of the storm not being far distant from Shields, where the barometer was standing at 28·31 inches, which is apparently the lowest reading recorded in the British Islands during the gale. . . . . In the neighbourhood of London the barometer fell to 28·47 inches, and there have only been seven years since 1811 in which the reading has fallen lower, the absolutely lowest corrected reading during the last eighty years in the vicinity of London being 28·02 inches on January 29th, 1814.'

The cause of storms and winds of all kinds is primarily the unequal heating of the surface of the earth by the sun's rays, but the way in which the final result is brought about is a matter of some discussion. Two main theories have been *proposed* to account for the phenomena. One, known as the

'convection' theory, is that the air in the centre of a cyclone rises in consequence of the greater relative warmth which is produced there by the latent heat set free by condensation of aqueous vapour. If an upward current is established by any cause at any locality other than very close to the equator, the eddying circular motion characteristic of cyclones must be produced. Another theory is that storms are circular eddies produced by the general motion of the atmosphere as a whole, just as eddies are formed in a stream of running water. An eddy thus produced in the upper strata of the atmosphere is accompanied by a diminution of pressure at the centre and so the air in lower strata rises and the effect may extend to the earth's surface.

Climate is the average of weather conditions and is mainly dependent upon :—

(1) The mean annual temperature and the range of temperature.
(2) The mean annual rainfall and its distribution throughout the year.
(3) The amount of bright sunshine.

Effect of Latitude.—If the earth were entirely covered with water or consisted wholly of land then the climate of any place would be determined by its latitude. Since the inequality of the lengths of the days and nights during the year increases with the latitude, the range of temperature is also subject to a general increase. But, that places having the same latitude have very different climates is apparent from the following table :—

	Latitude.	Average Summer Temperature.	Average Winter Temperature.	Range.
Lisbon	39°	71°	52°	19°
Pekin	40	81	27	54
Vienna	48	70	29	41
London...	51	64	37	27
Edinburgh	56	57	38	19
Moscow...	56	64	15	49
Aberdeen	57	59	39	20
Nain (Labrador) ...	57	47	0	47
Bergen (Norway)...	60	58	36	22
Yakutsk (Siberia)...	62	66	−45	111
Boothia Felix ...	70	38	−28	66
Mageröe	71	44	24	20
Melville Island ...	75	37	−32	69
Spitzbergen	78	45	5	40

It is evident, therefore, that other causes besides latitude determine the climate of a place, and also that places having the same average yearly temperature may have different climates. Thus, London and Vienna have nearly the same average temperature but very different ranges of temperature.

Effect of Elevation.—It has been pointed out that the average temperature decreases, and the range of temperature increases with the height above sea-level, and that even in the torrid zone the highest mountain peaks are always capped with snow. This fact is taken advantage of by Europeans in India, who recruit their health by retiring to the hills during the hot season; for by ascending some 3,000 feet on the Himalayas and Neilgherries a bracing atmosphere is obtained. Similarly, places situated on table-lands have a lower average temperature than other localities having the same latitude but not so elevated, whilst at the same time the range of temperature in such elevated stations is greater than at a lower level. Quito, situated 9,000 feet above sea level at the equator, and many other places on the Andes in South America, enjoy quite temperate climates on account of their elevated position.

The effect of large water surfaces is to decrease the range of temperature. The influence of the sea in this respect has already been referred to.

The effect of prevalent winds is to increase or diminish the average temperature, according as they flow from the equator or from the poles. The winds blowing from the interior of continents are liable to much greater extremes of temperature than the winds from water surfaces, being very hot in summer and very cold in winter. In England, we know that a north-easterly wind is cold, whilst a westerly wind is warm and moist. This is because in the former case the wind blows from higher latitudes, whilst in the latter, it blows from the equator and along the Atlantic. The west coasts of Europe and North America are rendered milder and moister by these south-west winds than corresponding latitudes inland and on the east coast.

Effect of the general slope of the land. The land which slopes towards the equator receives the sun's rays less obliquely than land sloping towards the poles. Hence in the northern hemisphere, the south sides of hills are warmer than the north sides; in the southern hemisphere, however, hills with a northward inclination are sloping towards the equator, so their

northern sides are warmer than the southern. It is on account of this cause, to some extent, that the height of the snow line lies at a different level on the north and south sides of the same hills and mountains. In North America most of the land north of latitude 50° slopes towards the poles; in Europe, however, only a small portion of the land has this northward slope, and this lies north of latitude 60°; this is one of the reasons why the climates of North America and Europe, even on the same parallels of latitude, are so different. A striking example of the influence of slope on climate is afforded in Asia. From the table-land of Central Asia there is a general slope southward and northward. On the southern side, tropical vegetation flourishes even at a height of 5,000 feet; but on the northern side the climate is considerably colder until Siberia is reached, where intense cold prevails all the year at places situated no further north than Edinburgh. Similarly, the southern side of the Alps has a magnificent climate, whilst the northern side, at the same elevation, is covered with ice. (Fig. 167.)

Fig. 167. Influence of Aspect on Climate.

The effect of mountain ranges varies according to whether the chain is parallel or inclined to the direction of the prevalent wind. It is fully considered in the section on rainfall.

The character of the land surface is very important. Rocky or sandy soils are subject to great extremes of temperature; they readily absorb the sun's heat and become extremely hot during the day and rapidly radiate the heat into space and thus become ice-cold during the night. The Sahara Desert is an example of a region having an extreme range of temperature.

The effect of drainage and cultivation is to increase the temperature and dryness, in fact, the increase in temperature due to drainage in Great Britain during the last hundred years is said to be from two to three degrees. Forests modify the heat of the sun during the day and prevent very rapid radiation during the night, and thus tend to equalise the temperature; but

they have also a cooling effect, being often associated with marshy land, for the trees act as condensers of the moisture in the atmosphere, and the rain that falls cannot flow freely off the land, but accumulates in low-lying parts; the air in contact with it is cooled, and there being no free circulation, it remains cool. As forests are cleared, however, and the amount of uncultivated land is decreased, the climate is made warmer, because the sun's rays are no longer cut off from the soil, and there is a freer circulation of air. The marshy region becomes a land covered with vegetation and traversed by a few rivers, and the climate is rendered drier because the condensers of atmospheric moisture have been demolished. The clearing of forest land, however, has often been carried too far, and a region luxuriant with vegetation rendered barren through lack of rain.

QUESTIONS ON CHAPTER XVIII.

1. Explain the manner in which land-breezes and sea-breezes are produced. (1885.)

2. Explain the cause of the difference of climate on the east and west coasts of Great Britain. (1884.)

3. How are the direction and force of the wind measured? (1884.)

4. What are the causes of the variations of pressure of the atmosphere? (1883.)

5. Describe land and sea breezes, and state how they are produced. (1882.)

6. What are isothermal lines? Explain how it is that isothermal lines do not coincide with the parallels of latitude. (1882.)

7. Explain the nature and cause of the difference between continental and insular climates. (1881.)

8. What is meant by the snow-line, and on what conditions does he height of the snow-line on different mountain chains depend? (1881.)

9. Why is the south-west wind in this country usually accompanied by rain, while the east wind brings dry weather? (1880.)

10. What are isobars? State the causes to which their continual changes in position are due. (1878.)

11. What are some of the characteristics of cyclonic and anti-cyclonic weather respectively?

CHAPTER XIX.

SPRINGS, RIVERS, GLACIERS AND LAKES.

Permeable and Impermeable Rocks.—We know from general observation that some substances will hold water whilst others cannot hold it so well. When a garden is watered the soil absorbs the liquid and it quickly disappears. If, however, we were watering a layer of clay we know that the water would not be so readily soaked up. Now substances that let moisture pass through them are said to be *permeable;* substances that prevent the passage of water are called *impermeable.* Chalk, sandstone, loose sand, and gravel are examples of the first, and clay and slate of the second, class of rocks.

Springs.—We have considered the moisture in the air and the various forms in which it is precipitated to the earth. It has also been shown that a considerable amount returns to the atmosphere again by evaporation. A portion runs off the surface into the watercourses, and in that way reaches the sea. A portion is absorbed by vegetation. And a fraction of the total

Fig. 168. A Surface Spring.

quantity fallen penetrates the soil and underlying formations to depths where evaporation has no influence. The character of the formation in which rainfall takes place, that of the fall itself, the amount of vegetation, the temperature, the slopes of the surface, and other circumstances will determine the quantity disposed of under each of the heads mentioned and this will vary

enormously under different conditions. Everyone is familiar with the springs that are met with at the side of many hills; and many persons have, when walking in dry weather, visited the spot where they once saw a spring bursting forth only to find it dried up, whilst in wet weather it flows copiously. It is evident, therefore, that some springs are dependent in some way upon rainfall. The rain-water absorbed by the earth sinks until an impermeable stratum is reached. It accumulates above this stratum and saturates the rocks above it to a height which increases with the amount of rainfall. If the strata are inclined, as in Fig. 168, the water slowly moves down the slope and reaches the surface through an outlet on the side of a hill or valley where the two kinds of rock meet.

Artesian Wells.—In the French province of Artois, some years ago, it was found that, by boring to a considerable depth in the ground, water rose out of the bore hole with great force after a certain depth had been reached. To understand the cause of this, consider the diagrammatic section across London shown in Fig. 169. Resting upon beds known as the upper and lower chalk, we have mostly impermeable or impervious clays. Where the edges of the strata reach the ground are called outcrops. Thus the upper chalk in the figure is shown to have outcrops at A and B.

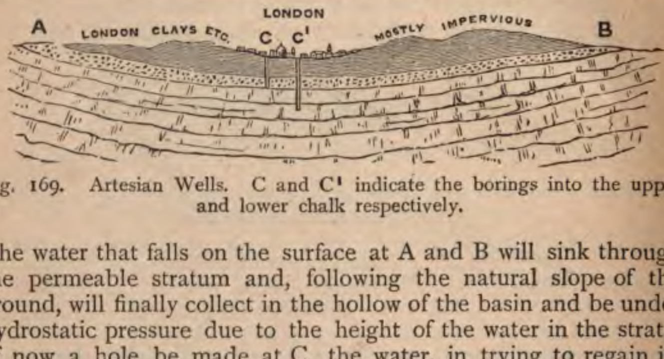


Fig. 169. Artesian Wells. C and C' indicate the borings into the upper and lower chalk respectively.

The water that falls on the surface at A and B will sink through the permeable stratum and, following the natural slope of the ground, will finally collect in the hollow of the basin and be under hydrostatic pressure due to the height of the water in the strata. If now a hole be made at C, the water, in trying to regain its level, will spurt out with a force dependent upon its level, the strata, and the point where the hole is made. The depth of the bore varies in different localities, and the water often comes from a distance of 60 or 70 miles. Such supplies of water are called *Artesian wells*, from the name of the town

where this method of boring was first used. There are hundreds of such wells now in existence. The increase in the number of deep wells sunk into the chalk by private individuals and others has caused a gradual lowering of water in this stratum, and it is now necessary to sink through the lower chalk until a water-bearing stratum is reached below it. The fountains in Trafalgar Square are fed by a boring which has a depth of 250 feet to the chalk and a depth of 135 feet in it. These depths are not, however, nearly so great as some in other localities, for at Grenelle one has been sunk to a depth of 1,800 feet, and delivers 650 gallons of water every minute.

The supply of water to the metropolis is derived from the Rivers Thames and Lea, from Chadwell Springs in the Lea Valley, and from deep wells in the chalk formation. The accompanying illustration (Fig. 170) shows the average daily supply

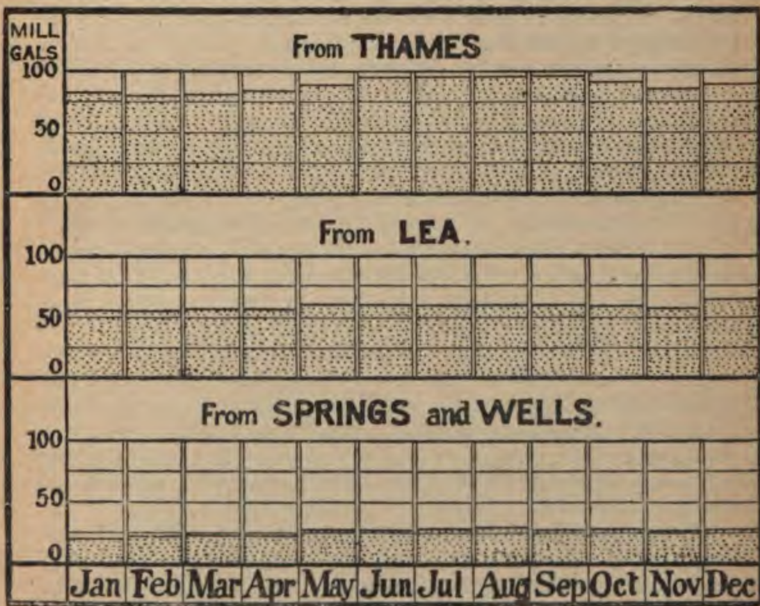


Fig. 170. Illustration of the variation in the supply of water to London in different months of the year.

from each of these sources, and it will be seen that springs and wells furnish a comparatively large amount of water. At one time the Kent Water Company derived about four million gallons of water daily from artesian wells. During the year 1890 this company abstracted from the chalk 4,525 million gallons, and the daily supply, during a part of January, 1891, reached 17 million gallons.

The Temperatures of Springs.—Variations in the temperature of the air only affect the soil and the rocks under it to a certain depth, which depth, however, must be very different in summer from what it is in winter, and very different in different parts of the earth. Beyond this depth of from 50 to 100 feet, the temperature is the same all the year round, and in our part of the globe is nearly equal to the mean annual temperature. At still greater depths the temperature is higher on account of the heated interior of the earth, and increases about one degree for every 60 feet of descent. Now since the water of a spring assumes the temperature of the rocks through which it percolates, a mere surface spring has a much different temperature in summer and in winter. If, however, a spring sinks to a moderate depth it has an almost constant temperature, only a small variation being caused as the water rises to the surface. Hence, by determining the temperature of springs, we may get a good approximation to the temperature of the rocks in which they occur; that is, we may get to know something of the temperature of the earth's interior.

The mineral substances in spring water consist chiefly of sulphates, carbonates, chlorides, sulphides and silicates of magnesium, calcium, potassium, sodium, manganese and iron. Some are held in solution by means of the carbon dioxide dissolved in the water. When some salt occurs in a relatively large proportion we get what are termed 'mineral' waters. The old sulphur well at Harrogate contains more than 1,000 grains of saline matter per gallon. Springs containing a compound of iron dissolved in them are termed *ferruginous* or *chalybeate* springs; those containing much carbonate of lime are called *calcareous*, whilst brine springs contain a large proportion of common salt.

The gases dissolved in spring water are chiefly nitrogen, oxygen, and carbon dioxide. Sulphur springs, like those at Harrogate, contain the disagreeable gas called sulphuretted hydrogen in solution.

The deposits of springs vary in character according to the nature of the dissolved material. Springs impregnated with

sulphuretted hydrogen frequently deposit sulphur, and calcareous springs deposit travertine. The *petrifying springs*, which are popularly supposed to turn any object placed in them into stone, are simply springs containing a considerable amount of dissolved carbonates. When a spring so constituted issues into the air, carbonate of lime is deposited on every object over which it passes, owing to a loss of carbonic acid gas by the water; an object such as a bird's nest, or a basket, left in the spray of such a spring soon gets coated with an incrustation of carbonate of lime, and is said to be petrified or turned into stone, although in reality it is only covered with a thin film.

Siliceous springs deposit *sinter*. The geysers and hot springs of Yellowstone Park, in the Rocky Mountains, bring up enormous quantities of dissolved silica. It will be remembered, however, that pure water does not dissolve silica to any appreciable amount, although it is able to do so when alkaline. The highly heated water probably becomes alkaline in character by the decomposition of felspar and igneous rocks containing soda or potash, and is thus able to hold the silica in solution. The silica is then deposited around the opening out of which the geyser or hot spring rises. Recently, however, evidence has been brought forward which indicates that the silica is really secreted by algae capable of living in hot water, and then deposited when the organism dies. Some terraces formed by deposits of sinter are shown in Fig. 113.

Rivers.—A few definitions relating to rivers will now be given, the proper treatment of which belongs more to Geography than Physiography. Dr. Haughton has remarked that a river is:—

'The surplus of rainfall over evaporation, seeking its way down to the sea level by the *path of least resistance*, which is the path of *greatest slope* or valley line.

'Each river drains an area called its *rain-basin*, and the boundary lines of the rain-basins are called *water-sheds*, or lines of *least-slope*, or *ridge-lines*.'

The Source or Rise of a river is its highest, or longest, or most important water supply.

The Bed or Channel of a River is the hollow which it has scooped out in the land.

The Banks of a River are the margins of the channel in which it flows. On following a river towards the mouth, the *right bank* is that on the right hand, and the *left bank* is that on the left hand.

An Affluent or Tributary Stream is one that flows into a larger

one. The point where the junction takes place is called their *Confluence*.

The Mouth of a River is where the water is discharged into a lake, estuary, or sea.

The substances dissolved in Rivers.—River waters always contain more suspended matter than spring water, and tend to throw the dissolved carbonates out of solution on account of the diffusion of the carbon dioxide. The comparative composition of the Thames and Trent waters, represented by the number of grains per gallon of matter in solution, is shown in the following table:—

	Thames.	Trent.
Carbonate of Lime ...	10·80	0·32
Sulphate " ...	3·00	21·55
Carbonate of Magnesium	1·25	5·66
Chloride of Sodium ...	1·80	17·63
Silica	0·56	0·72
Organic Matter	2·36	3·68
	19·77	49·56

Periodic Fluctuations of the Volume of Rivers.—The facts that brooks dry up, rivers diminish in volume, springs cease during a drought, and that sudden and continuous rainfall causes rivers to become swollen and sometimes overflow their banks, prove very conclusively that all such volumes of water are very dependent upon the precipitation of moisture from the atmosphere. In those countries where regular seasons of wet and dry weather occur, the springs, brooks, and rivers periodically rise and fall. The volume of all large streams fluctuates with the season; in some streams, however, the change is much more noticeable than in others. This periodic rise and fall is well marked in the case of the Nile and Ganges. The former river shows a sensible rise at Cairo about the beginning of July, which continues until the end of September, when a maximum of from 20 to 30 feet above the June level is reached. A constant level is maintained for about a fortnight, then the level decreases; on November 10th half the maximum height is reached, and at the end of November the true inundation has ceased. This rise and fall occurs with perfect regularity every year, and was a subject of much discussion with the ancients, who thought it was caused by the melting of snows. This theory is correct to a certain extent, but the true cause is that

the high and rocky table land of Abyssinia is visited by heavy rains during the months of March and April; these rains create torrents of water in the numerous mountain gorges, which rush down and swell the Blue Nile. The periodicity of the rainfall thus causes the regular rise and fall of the river.

The Ganges rises from May till September, owing to the melting of snow on the Himalayas, and the occurrence of the wet monsoon. Similarly, the Rhine and the Rhone, whose sources are the snows and glaciers of the Alps, increase considerably in volume during the summer and shrink during the cold and often wet months of the year.

Glaciers are rivers of ice draining a tract above the limit of perpetual snow, and removing the superabundant snow to regions below this limit. This formation is more fully defined as being a solid mass of frozen water, the upper part of which is loose snow, the middle semi-consolidated ice, and the lower of ice, properly so-called, which mass is either contained in a single mountain valley, or formed of several converging portions, filling several radiating subsidiary valleys, and uniting in one mass in the main depression.

During the summer some of the snow is melted, the water formed trickles down through the mass and gets frozen on to the granules which it meets colder than itself. By this process, assisted by the consolidating influence of pressure, there is formed a mass of white, opaque, frozen and consolidated, half snow, half ice, which the French call névé, and the Germans firn.

The Motion of Glaciers.—That the glacier really moves is capable of easy demonstration by fixing a row of stakes or stones straight across it to some fixed points on the banks. In a few days the row will have become curved, and all the stakes or stones will be found to be lower down when observed with respect to the bank. (Fig. 171.) The velocity of a river is always greatest in the middle, and least at the sides and bottom, owing to friction; for the same reason a glacier moves fastest at the centre and slowest at the sides and bottom, the result being that the row of stakes or stones laid down to investigate the motion becomes curved. The rate of

Fig. 171. A, a straight row of stakes laid across a Glacier; B, the same stakes a few days later.

motion depends to a slight extent upon the slope of the valley down which a glacier is travelling. It also depends on the pressure of the rear portion, and therefore on the amount of snow-fall. The large glacier of Chamouni, called the Mer de Glace, moves on the average about 24 inches in the centre for about 16 inches at the sides during 24 hours. The Greenland glaciers move much faster than this, the Muir Glacier, in Alaska, entering the sea in summer at the rate of 70 feet a day in the centre, and 10 feet in the margins. The rate of movement of all glaciers is least in the winter.

The formation of Crevasses in Glaciers.—When a river experiences a sudden fall the mobility of the water allows it to flow over in an unbroken stream as a water-fall. When there is a sudden fall in the level of the valley traversed by a glacier or ice-river an ice-fall is formed, but ice is not so mobile as water, hence this alteration in the level of the bed causes it to break up to a certain extent as it glides over, and crevasses are produced. Similarly, such splits are produced by the bending of a glacier from side to side, hence the surface of a glacier is rarely even, and wide chasms are often formed, which extend to the bottom.

The reason why glaciers flow as if they were constituted of a yielding material has been a matter of much discussion. Professor Tyndall believes that the ice is continually being cracked and cemented together again by regelation. The balance of evidence, however, seems to prove that glacier ice is not a rigid body, but a plastic one, and that it behaves like sealing-wax and other similar substances which mould themselves in time to the surfaces on which they lie, and maintain, meanwhile, the quality of excessive brittleness under a blow or rapid change of form, such as lead to the production of crevasses.

The motion of a glacier is therefore due: (1) to the actual flow of its substance, which goes on continuously; (2) to a certain sliding over its bed; and, (3) certain more sudden movements due to large masses cracking under great tension. The first is no doubt much the most important of these causes.

All large bodies of water surrounded by land and not directly connected with the sea are called lakes.—When the slopes of a country are fairly uniform the surface waters are carried into seas and oceans by streams and rivers. But if an unusual depression of the land surface occurs, the waters accumulate in it and form lakes or sometimes wet marshy ground *called morasses.* An inspection of a map of the globe shows

that lakes are most numerous in the north temperate zone; in fact, the great lakes of North America, the Caspian Sea, Lake Aral, Lake Balkash, and Lake Baikal in Asia, form a circle of enclosed collections of water. Many lakes lie in hollows scooped out of the solid rock. These usually occur in high latitudes, and there is evidence that they have been formed by glacier action. The scratchings and general character of the adjacent rocks often demonstrate the movements of ice that must have occurred. It is doubtful, however, whether glaciers can scoop holes in solid rocks, and the more probable supposition is that such rock basins existed before the glacier movement and were filled with decomposed rock material which was scooped out by the action of the glacier ice. When a glacier retreats up the valley owing to a diminished snow-fall and a warm season in the locality, a heap of stones and rubbish is left which dams up the valley so that the water from the melting ice forms a lake; indeed, the lake of Geneva is largely fed by the melting of the ice of a glacier. Other lakes are found, not in solid rock nor in a rocky valley, stopped up at the lower end, but lying among the rocks and earth once borne on the surface of a glacier and deposited as the ice melted.

Some lakes, like those in Central Italy, are found in volcanic districts, filling up the craters of extinct volcanoes or the openings that have been formed by eruptions.

Lakes may thus be classified with respect to their occurrence as follows:—

(1) Those occurring in hollows scooped out of solid rock.
(2) Those enclosed among heaps of glacier drift.
(3) In vast table-land depressions where there is a copious rain-fall.
(4) Along low and sandy sea-coasts.
(5) In craters of extinct volcanoes and cavities formed by explosions.

The waters of lakes.—When the waters of a lake rise, an outlet for the surplus water may or may not be found. In the latter case, if the land surrounding the lake has little slope there will be a much greater area of water surface when the level of the lake is high than when it is low, hence there will be a much greater amount of water lost by evaporation and this may equal the amount brought into the lake. When a lake having no outlet keeps at a constant level the evaporation from its surface equals the supply brought by the tributaries. If there is an excess of

evaporation over supply owing to the exposure of a large water surface, this goes on until the lake has fallen to such a level that the evaporation from its surface is equal to the supply of water. In the case of the Dead Sea this process has been carried so far that its level is 1,350 feet below the level of the Mediterranean. The Caspian Sea covers a surface larger than the British Isles, and its surface is 85 feet below sea-level.

Lakes having an outlet contain fresh water, those having no outlet contain brackish water.—Now when a lake has an outlet, the water in it, like the water of its tributaries, is fresh; lakes having no outlet, however, contain salt, bitter water. The latter class of lakes is supplied with water by the many streams which run into them but sends no rivers out. We know, from what has been previously said, that all streams contain a certain amount of mineral matter; such dissolved matters are, therefore, carried into lakes. If the lake has no outlet and the level of the water does not rise, we know that the surplus water is being carried off by evaporation into the atmosphere; but water-vapour, be it formed by slow or rapid evaporation, is always pure, hence a lake without an outlet is constantly losing pure water by evaporation and the dissolved salts are being left behind. Such lakes, therefore, gradually get more salt and bitter, until—when the water has become saturated with any particular salt—the continuation of evaporation causes it to be deposited in a layer at the bottom of the lake.

Some examples of salt water lakes and seas of the character described are the Caspian Sea, Dead Sea, the Sea of Aral and the Great Salt Lake in North America. A pound of water taken from the Dead Sea and carefully evaporated would leave behind a quarter of a pound of solid matter, which is about seven times the amount that would be found in ordinary sea water; of this about 25 per cent. would be common salt, and about 75 per cent. chlorides and sulphates of calcium and magnesium. A pound of water from the Great Salt Lake would on evaporation be found to leave nearly 2½ ounces of solid matter, 79 per cent. of which would consist of common salt, about 10 per cent. chlorides and sulphates of calcium and magnesium, and the remaining 11 per cent. would be made up of various other substances. (Figs. 172 and 173.)

In the case of ordinary river water and the water of such *lakes as Lake* Superior and Lake Michigan in North America, *the proportion that* common salt bears to the total dissolved solids

is only a little over 3 per cent., carbonates of calcium and magnesium about 70 per cent., and various other substances make up the remaining 27 per cent. From a comparison of these facts, therefore, it appears that chlorides and sulphates of calcium and magnesium form the largest proportion of the mineral matter in so-called salt water lakes and seas, and carbonates of these elements occur in the greatest proportion in the average fresh water lakes.

Composition by weight of water from the

Dead Sea. Great Salt Lake.

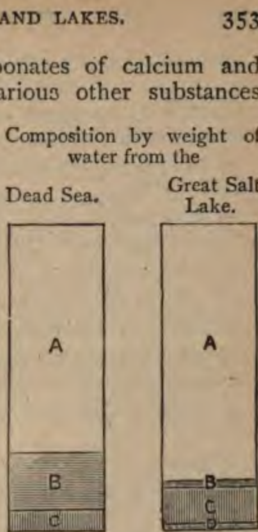


Fig. 172. Fig. 173.

A, water; B, chlorides and sulphates of calcium and magnesium; C, common salt; D, various salts.

Solid matter is deposited in lakes owing to the checking of the current of their tributaries.—It is evident, therefore, that the bottom of all lakes must be rising, and that all such bodies of water must get filled up and form rich *alluvial plains* or *lake-lands*. An examination of the course of a river would show that in places it runs across plains of alluvial land that have become covered with grass and converted into green meadows. The hollows doubtless represent wider parts of the track in which the river once flowed; as the moving water spread out over the larger area its velocity was decreased and sediment was deposited, the result being that the hollow was gradually transformed into an alluvial plain traversed by a river of the ordinary form.

A lake acts as a preventive of floods.—The water from the tributary streams spreads out over such a large area that even when the supply is enormously increased the effect on the out-flowing river is not great. The presence of large sheets of water also serves to equalise the temperature during the different seasons of the year. In the summer the water does not get hot so quickly as the land, and in the winter it does not lose its heat so readily, so that it cools the air in summer and warms it in winter. In fact, it has been calculated that during five cold nights of December, 1879, the Lake of Geneva gave out to the atmosphere as much heat as would have resulted from burning 1,200,000 tons of coal.

QUESTIONS ON CHAPTER XIX.

1. How do the waters of springs, rivers, and the sea differ from pure water? (1886.)

2. In what respects does the water of the seas differ from that of rivers and lakes? (1883.)

3. How has it been proved that glaciers move, and what facts do you know of glacier movement? (1882.)

4. What is meant by the snow-line? Why is the snow-line sometimes higher on one side of a mountain chain than on the other? (1877.)

5. Describe the principle of artesian wells.

6. What is a so-called petrifying spring? What is sinter? How is it that the water of certain hot springs is able to hold silica in solution?

7. What do you know of the periodic rise and fall of the Nile, and its cause?

8. How may lakes be classified according to their mode of occurrence? Why do lakes having no outlet always contain brackish water?

CHAPTER XX.

AGENTS WHICH PRODUCE CHANGES IN THE FORM OF THE EARTH'S CRUST.

The nature of soil varies considerably.—This is easily seen by examining the layers of soil beneath the superficial covering of vegetation in different places. In some cases the soil, or ground as it is commonly called, is of a stiff clayey nature and difficult to work, in others it is full of sand or gravel, so that only hardy varieties of plants will flourish upon it; or it is calcareous, *that* is, contains a large proportion of carbonate of lime. A large *quantity of* humus, or vegetable mould, occurs mixed with the

sand or clay and forms material essential for the growth of most plants. When this ingredient is exhausted by numerous cultivations of crops the soil has to be fertilised by manures. It appears probable, however, that humus must be regarded as a consequence rather than a cause of fertility.

Soil consists mainly of fragments of rocks.—When the decayed organic matter is removed from soil, that which remains is seen to be particles evidently produced by the breaking up of rocks. In general the grains have been derived from the rocks of the district in which they occur, and, if a pit be dug, large fragments of the same material would be reached a few feet below the surface. This is known as the 'subsoil.' Some of the roots of large plants may penetrate down so far, but they are mostly contained in the layer of soil above it. (Fig. 174.)

Fig. 174. Formation of Soil: *a*, beds of rock tilted on end; *b*, the same broken up by the penetration of tree and other roots; *c*, mould formed by this material disintegrated by the weather and by mixture with decayed vegetation.

Beneath the subsoil is found the solid rock. This gradual increase in size of fragments having the same constitution from the soil downwards indicates that the underlying rock has decomposed and furnished the materials of the subsoil and soil above it. Hence, in such cases, the character of a soil, and, therefore, that of the vegetation which best grows upon it, varies with the nature of the rock from which it has been produced. Some soils, however, have drifted from the place in which they were formed and overlie rocks which have a different constitution. Numerous agencies bring about the disintegration of rocks. They are change of temperature, the atmosphere, the ocean, and running water. And, finally, earthworms and the growth of plants exert forces which cause considerable changes to take place.

The forces which tend to produce changes in the earth's crust are divided as follows:—

(1) *Atmospheric.* The wearing away of rocks by the action of the air, winds, solar heat, snow, frosts, and ice.

(2) *Aqueous.* Rain, springs, rivers, waves, tides, and ocean currents.

(3) *Organic.* Arising from plant and animal growth, such as peat-mosses, jungle and swamp growth, earth-worms, coral reefs, and foraminiferal accumulations.

(4) *Igneous.* Arising from internal forces and causing volcanic eruptions, earthquakes, and slow movements of upheaval and depression.

By the chemical and mechanical action of the external forces rocks are broken or crumbled into powder or *debris*, the process being known as *disintegration*. *Transport* is the word used to express the carrying away of disintegrated materials. *Disintegration* and transport constitute *erosion*. The result of erosion is termed *denudation*. *Sub-aerial* denudation is produced by atmospheric action, and therefore *pluvial* denudation, or that brought about by rain, comes under this head. It also includes *fluviatile* denudation by rivers. *Marine* denudation is produced by the action of the sea, and *glacial* denudation by that of ice.

The chief agency causing disintegration of rocks is solar heat.—Rocks expand with heat and contract when the temperature is lowered. The consequence of these alternate expansions and contractions is that numerous cracks are produced, and fragments loosened. Livingstone recorded that at a place 12° south of the Equator the range of temperature in 24 hours was 127° F., which occasionally caused pieces of rock weighing from a few ounces up to 200 lbs. to break away from the main mass. And it has been found impossible to cement together greater lengths of stone than 5 feet so as to render the joints water-tight in a place where the range exceeds 90° F. in 24 hours. The effects of great range of temperature are of course most clearly seen in tropical countries, where the rocks are extremely hot by day, whilst at night the radiation from their surface is often so rapid that sometimes water placed upon them in a shallow vessel is frozen.

Water is a great agent of disintegration.—It acts both mechanically and chemically. When water sinks into rocks resting upon a layer of clay or similar material an enormous pressure may be produced depending on the height at which *the level* of the water in the fissures is above the clay. *But the freezing* of water produces the greatest mechanical effect.

It has been shown in Chapter IV. that water expands when it freezes. Hence, when water which has percolated through rocks and filled up cracks and crevices is reduced to the freezing point it expands and pushes aside and breaks up the rock. This action is especially noticeable in mountain ranges, where large quantities of angular fragments are fractured every winter. And the effects on a small scale, although not so readily noticeable, are more extensive. Water acts chemically in the disintegration of rocks by forming hydrated oxides, silicates, &c., which take up a greater or smaller amount of room than the original compounds. It is also a powerful solvent and so dissolves away many rocks. The fragments that get broken off by any such action accumulate at the place of formation. If this be a cliff, the accumulation of detritus at the base is known as a 'talus.' A fine example of a

Fig. 175. A Talus. (*From a Photograph* by Wilson of Aberdeen.)

formation of this character is shown in Fig. 175. Similar accumulations extending down a slope instead of along the base of a cliff are known as 'screes.'

Wind assists in the breaking up of rocks by causing particles of sand to impinge upon them. In certain places the lighthouses are only maintained with difficulty, as the whole of the glass is roughened by the wind driving particles against it. This fact is now utilized in the arts. A jet of steam and quartz or emery particles is made to impinge on glass covered in some parts and bare in others. The result is that the bare parts get a frosted appearance, whilst those that are covered remain unaltered, and so a sort of stencil pattern is produced. Sand particles so used, whether naturally or artificially, become perfectly rounded and polished.

The action of rain is strikingly seen in Tyrol, where there are numerous pillars of clay, each capped by pieces of hard rock as in Fig. 176. The blocks of stone once existed mixed with clay

Fig. 176. Earth Pillars or Pyramids in the valley of the Finsterbach, near Botzen, South Tyrol.

and earth in a valley. Rain has gradually worn away much of the original mass, but the portions under the blocks being protected from this action, more or less conical 'earth pillars' have been formed, some of which occasionally reach a height of 100 feet. If the surmounting piece of rock be removed by any means, the earth pillar soon crumbles away.

River-Valleys.—Brooks, streams, and rivers are constantly eroding the land over which they flow, and so cutting out valleys. The average rate at which rivers lower their basins is 1 foot in 3,000 years, and if this rate be maintained, and the average height of the land above sea-level be taken as 1,000 feet, then the present dry land surface of our globe will be totally removed in 3,000,000 years. In the neighbourhood of mountain chains the rain that falls creates torrents of water, which flowing down the sides scoop out valleys transverse to the direction of the chain. These are termed *Transverse* or *Primary* valleys. All such torrents flow towards valleys more or less parallel with the chain and termed *Longitudinal* or *Secondary*, and act as feeders to main streams, hence, generally speaking, a longitudinal valley has not such a great slope as a transverse one.

The Primary valleys being due in the first instance to the comparative steepness of the slopes of the original flanks of the mountain chain, cut directly across all bands of rock that run parallel to the length of the chain, independently of their hardness or softness. Where a hard rock is crossed, the sides of the valley are more precipitous than in the case of soft ones. For the softer and more easily eroded banks of the stream tend to slide down the slopes and consequently to widen the valley. The longitudinal valleys originate in soft or more easily destructible bands of rock, and are therefore wider and more regular than the transverse ones.

A good example of a river valley may be seen at Bristol. At one time there was a gradual slope towards the west of a plateau known as Clifton and Durdham Downs. The young Avon then flowed in a minor inequality of the surface towards the Severn on the west and continually deepened its channel, the result being that now the Avon flows in a gorge more than two hundred feet below the level of the land on either side.

Cañons.—In regions where the rainfall is slight, a very steep gorge may be formed by the action of running water. The most wonderful instances of this kind of erosion are found along the

This kind of excavation must go on in every case where water falls over a precipice, and although the cataract may appear to occupy the same place from year to year it is slowly creeping up stream and carving out a ravine as it does so. From a comparison of the results as to the position of the Niagara Falls made in 1842 with some observations made in 1890, it has been found that

Fig. 179. Example of River Erosion. The gorge A B has been worn away by the river.

the annual recession at the American Fall is 7·68 inches, and at the Canadian or Horse Shoe Fall, 2 feet 2·16 inches. During the period of 48 years the area of rock which has been worn away is 32,900 square feet at the American, and 275,400 square feet at the Canadian, Fall.

Marine Denudation has been referred to on p. 263. The methods by which the sea coast is wasted away by breakers can be summed up under the following heads:—

(1) By the energy of the advancing mass of water.
(2) By dashing the pebbles and shingle against the cliffs.
(3) By water filling the fissures and joints of the rocks and being driven in with great force by the waves and expelled with nearly equal force.
(4) By solution.

Along most of our coasts the sub-aerial agencies work quicker than the waves, and consequently the cliffs slope backwards from the shore, the sea being chiefly occupied in breaking up and washing away the fragments from the cliffs, thus leaving fresh surfaces exposed to the attacks of atmospheric erosion. This is

Fig. 180. Island of Borerray, St. Kilda.

Illustration of aerial and marine denudation. The former has been the most active, even though the rock is exposed to the full force of the Atlantic. (*From a Photograph by Wilson of Aberdeen.*)

often very noticeable, as is shown in Fig. 180, which represents the Island of Borerray, St. Kilda. The sub-aerial denudation has evidently been more active than the marine, even though the island is exposed to the full force of Atlantic breakers.

Changes produced by Organisms.—The living things upon the earth are divided into two great groups, viz., plants and animals. It is found that plants absorb carbon dioxide, hydrogen, nitrogen, and oxygen from the air and transform them into the complex substances necessary to support life. Animals have not this power of manufacturing organic compounds from inorganic substances, but live by feeding upon plants and upon one another. Plants obtain a great amount of the necessary nitrogen from the soil, for they will not grow so well in soils free from nitrogenous matter. Both plants and animals return to the atmosphere the materials of which they are composed,

in the form of water, carbon dioxide, oxygen, &c. Carbon, which, in the case of plants, arises from the decomposition of carbon dioxide, is not so returned, however, but is eventually buried and so accumulates in the crust of the earth. It is by the gradual loss of hydrogen, oxygen, and nitrogen that we get mosses passing into peat, peat into lignite, and so on into coal and graphite.

The building of banks along the sea shore, and the cutting of embankments and canals are some of the results of human agency, but they are insignificant when compared with those produced by the lower organisms. Some of the work of disintegration by plant growth is due to the thrusting down of the roots into rocks. In addition to this mechanical action, plants act chemically by the absorption of mineral substances from the rocks and by the production of certain acids. Certain animals do a great deal of work by boring into rocks. Earthworms eat soil for the sake of its nutriment, and reject the inorganic and useless portions in the form of casts. Charles Darwin found that in many parts of England a weight of more than 10 tons of dry earth annually passes through the bodies of these lowly organisms and is brought to the surface in each acre of land, so that the whole superficial bed of vegetable mould passes through their bodies in the course of every few years. And not only are soils moved in this manner, for it has been found that, over an acre, nearly 2,000 tons of sand were brought up by lobworms in the course of a year and deposited at the surface. Fresh sand was thus continually being introduced to the action of the waves and wind.

Mention has already been made (p. 198) of the accumulations due to corals and foraminifera. This is the most important action of organisms, but material is also sometimes transported by them.

The transport of detritus goes on simultaneously with the disintegration. One of the agents producing it is gravitation. Landslips are caused by the sliding down of masses of rock resting on inclined strata, and the movement is produced by the action of gravity. Previous to a landslip the ground is loosened by one or more of the following means:—(1) frost, (2) the percolation and accumulation of water, (3) the weathering action of wind and rain, and (4) earthquakes. Continuous winds are great agents of transport. Along some flat portions of coast lines the sand is blown inland, and forms the undulating hillocks, *termed* 'sand-dunes,' such as those of Carmarthen and the West *Coast of* France. Fine dust, such as that which results from *volcanic* explosions, is often carried very great distances by winds.

The Transport of Detritus by Moving Water.—Rain washes particles of soil downwards; indeed, this action is sometimes so great on the side of a hill that the soil is only prevented from being washed away altogether by making terraces. Rivers do transporting work by carrying down to the sea materials dissolved in the water, or suspended in it, or by rolling fragments along its bed. The Thames carries past Kingston about 1,520 tons of dissolved and, therefore, invisible mineral matter every day. About 1,000 tons of this is carbonate of lime, derived chiefly from the Cotswold Hills, and about 250 tons is sulphate of lime (gypsum). Besides this, there is a large quantity of matter held in suspension. It is the suspension of solid particles that gives colour to the water of rivers, the colour being dependent upon the nature of the rocks in the course. As the solid particles are hurried down stream they are reduced to fine sand or mud, and the channel is constantly being enlarged; sometimes the suspended material is caught in eddies and whirled round to form what are known as *pot-holes* in the bed. The Mississippi carries down to the Gulf of Mexico nearly 1,000,000 tons of solid matter in suspension every day, and besides the suspended matter, it is estimated that 75,000,000 cubic feet of earth, sand, and gravel are pushed along the bottom into the Gulf of Mexico every year, whilst these amounts are considerably increased during floods. The Ganges carries about 335,000,000 tons of mud past Ghazipur during the four rainy months, which amount is on the average $\frac{1}{430}$ of the weight of the average water discharge for the same period.

The conditions favourable to the carrying of sediment by running water may be summed up as follows:—

(1.) Size and shape of particles. The smaller particles will be carried most easily and farthest.

(2.) Specific gravity of the particles. The lightest will be carried farthest.

(3.) Slope of the river bed. This affects the velocity of the current, and as the carrying power of water varies as the sixth power of the velocity, a stream which flows down a highly inclined bed carries down much more sediment than one which flows through a flat country. With double the velocity the carrying power is 64 times as great, with treble the velocity 729 times.

(4.) The curvature of the course. The velocity of a river is checked by the curvatures, and hence the power of carrying sediment diminished.

(5.) The nature of the bed, *i.e.*, its hardness or softness, roughness, &c.

The Lowering of River Basins.—Since the solid matter carried into the sea by rivers represents the amount obtained from the whole area drained by the river, it is possible to calculate the amount the general surface of the land has been lowered to supply the material.

At the present rate of denudation the Cotswold Hills are having their height lowered by about 76 feet in a million years. The rainfall of the Upper Ganges removes one foot from the whole surface of its rain-basin above Ghazipur in about 1,150 years. The area of the basin of the Mississippi is 1,244,000 square miles, and it has been calculated that 'If the material brought down in suspension and solution in one year were spread over its basin it would cover it to a height of $\frac{1}{4566}$ of a foot if retained in the soft form, or $\frac{1}{6000}$ of a foot if made into a solid.' Hence the Mississippi lowers its basin by one foot in 4,566 years. The Rhone is estimated to remove one foot in 1,528 years, the Danube one foot in 6,820 years, and the Po one foot in 727 years.

Transport of Detritus by Glaciers.—One or more continuous lines of stones and earth occur along the middle of a glacier, and similar lines may also be seen at the sides. These represent work done by glaciers in the transportation of materials from a higher to a lower level. A river carries solid matter in suspension, a glacier carries downwards on its surface the debris which falls upon it. For weathering is constantly going on all along the sides of the rocky valleys traversed by rivers of water or rivers of ice; fragments of rock, therefore, are constantly being loosened and fall upon the sides of the glacier, forming lateral moraines which are borne down the valley. The transport of detritus by icebergs and the ice-foot has already been alluded to (p. 281).

Moraines.—The lines of stones that run along the sides of a glacier are called *lateral moraines*, those that lie along the centre are *medial moraines*, and that deposited at the end is called a *terminal moraine*.

If a medial moraine be traced upwards it will be seen to be formed by the meeting of two of the lateral moraines of separate

glaciers running into one. The mode of formation is shown in Fig. 181. The quantity of material upon a glacier is sometimes so great that the ice is completely covered, nevertheless the glacier continues on its downward course.

The rocks carried on the surface of a glacier, and those in the mass of ice itself, are carried downward until a point is reached where the ice is continually being melted. This point is not at the same height above sea level as the snow-line; but a point is always reached by a glacier where it slowly melts away

Fig. 181. Formation of Lateral and Medial Moraines.

into a stream of muddy water. The milky appearance of the water is due to the suspension in it of the particles formed by the grinding action against the surface of the glacier bed. A glacier thus becomes the source of a river and such a river will become more swollen in the summer, when there is more of the glacier melted away, than in winter. As the ice melts, the material carried down by the glacier is deposited and forms a heap of stones and earth called a terminal moraine. (Fig. 182.)

Terminal moraines may be formed in the sea when a glacier ends there (*see* p. 281). These moraines, and also the material which accumulates in hollow portions of the glacier-valley, consist of a kind of clay containing large blocks of stone, the mixture being called 'Boulder Clay.'

Fig. 182. Ice Cave at the end of the Ober Grindelwald Glacier.
Width, about 30 yards; distance from the back to the mouth, about 10 yards.
(*From a Photograph taken by Mr. W. Kirman, September, 1891.*)

Glacial Striation.—In addition to the material transported downwards on the surface of a glacier, portions of rock fall into crevasses and are carried in the ice, or reach the bottom of the glacier. Such fragments wedged in the glacier share its motion, and, as they are dragged along the sides and bottom of the glacier bed are scratched and ground up as if innumerable files and rasps were at work upon it, all sharp corners are rubbed ff and the valley down which the glacier flows gets more or less nooth. The striations or scratchings on the surface of the rock at

the sides and bottom of a glacier are therefore parallel and have a general direction down the valley. (Fig. 183.) From this fact it is possible to recognise where glaciers have formerly existed, and the direction in which they moved; and the distribution of such striated and smoothed rocks in Northern Europe and North

Fig. 183.- Ice-scratched (Striated) Rocks.

America show that these two parts of the earth have been under moving sheets of land ice, the same as Greenland is to-day. An ice-polished block called an 'erratic,' on which glacier striations are plainly visible, is shown in Fig. 184. This block, like the boulders in Fig. 185, has been carried by a glacier, and was deposited as the ice melted.

Roches Moutonnées and Glacial Drift.—A glacier retreats and gradually leaves bare the valley in which it moved, when the ice is melted quicker than it is supplied from the snow-field at the top. We may then see the effects of the motion of the glacier upon the rocks in its bed. No angular masses of rock can be found, for the grinding action previously referred to smoothes and rounds them, so that they appear like the backs of a lot of sheep. Indeed such round-topped rocks are known as *roches moutonnées* (sheep rocks). It is by the finding of these

Fig. 184. Cumberland Stone, Culloden Moor, Inverness-shire. An Ice-polished 'Erratic.' (*From a Photograph by Wilson of Aberdeen.*)

Fig. 185. Boulders left by the melting of a glacier.

and similar striated rocks in the Lake district and Scotland that we know Britain was once covered with ice. Besides the striated rocks that occur along the bottom and sides of the valley of an ancient glacier, all the material which was originally carried on the surface is deposited as the ice melts, and, as the glacier gradually creeps up the valley, material called *glacial drift* is distributed along the bottom. The masses of rock that fall upon the surface of a glacier are thus often transported to regions where none of the same character occurs.

Rock Tables.—If a lump of ice be placed in one pan of a balance kept at the temperature of freezing water, and weights put in the other pan so as exactly to keep it in equilibrium, after a time the pan of the balance which contains the weights will go down, thus indicating that the ice has lost in weight; this is because some of it has evaporated. In like manner all glaciers experience a loss by evaporation from their surface, and this lowering of the surface is called the *ablation of the surface*.

Fig. 186. Rock-tables.

That the surface is constantly being lowered is made evident by the fact that many large blocks of rocks are found perched upon a pedestal of ice, often ten or more feet high. Some of these 'rock-tables' are shown in Fig. 186, the ice has melted and evaporated all around the rock, but so much evaporation cannot go on under it, hence the rock grows up, as it were, out of the ice, although really it is the surface around the rock that sinks; after a time the pedestal becomes too slim to support the rock, which is therefore dropped upon the ice to again be raised up as formerly.

The evidences of glaciation, which are preserved for a long period of time under suitable conditions, consist of, (1) smoothed and striated rock surfaces, if buried beneath fine sediment, (2) smoothed, faceted, and striated boulders, and (3) scattered boulders or large rock fragments perched on the sides or summit of a mountain. (Fig. 187.)

Fig. 187. Perched Block, left by the melting of a Glacier.

Deposits in river beds.—When the bed of a river widens and the velocity of the current slackens, the solid particles can no longer be held in suspension, thus much of it is deposited on the bottom of the river. After a river has flooded and gone down, the meadows and the flood plain altogether are left covered with a layer of fine mud or sand. The matter thus deposited by rivers

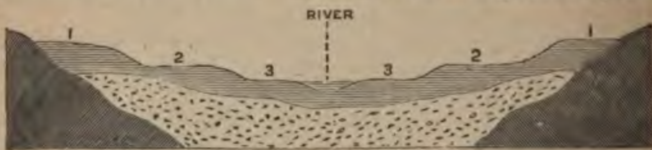


Fig. 188. The Valley of a River. 1, 1, 2, 2, 3, 3, represent river terraces at different times.

is called *alluvium or alluvial deposits.* It is evident that the heaviest substances suspended in the water will be the first deposited and that the lightest substances will be deposited on the top. Such successive depositions raise the level of the surrounding land, whilst the river channel is being deepened at the same time. The result is, that a time comes when the flood of water cannot overflow the sides of the river, so it eats into the soils bordering it. This goes on during many years, the higher portions of the banks being carved out with each increase in

the volume of the water, and eventually another flood plain is formed at a lower level than the first, and so on until a series of flood plains or river terraces is formed. These terraces are, therefore, made up of the mud, sand, and gravel deposited by rivers. (Fig. 188.) The formation may not be strikingly marked, but there is always a gentle slope from the deep channel in which a river flows to high land on either side.

Fig. 189. Corrie-na-baich, Glencoe. Delta of a little stream filling up a lake. The house is obviously on the delta. (*From a Photograph by Wilson of Aberdeen.*)

Deposits in lakes or lacustrine deposits.—The river Rhone enters the lake of Geneva as a swift and turbid stream and leaves it clear and transparent, having deposited at the upper end of the lake soil brought from the Alpine slopes. Similar deposits occur when any river runs into the still waters of any lake; and the amount of deposit is, of course, greatest where the river meets the lake. At this point a kind of bar is formed which daily increases in size, and in time gets so high as to be above flood level. As the deposition goes gradually on, the bar creeps out into the lake. Fig. 189 shows the deposit of a little stream, filling up a lake in this manner. No better example of this action can be quoted than that of Port Valais, which once existed as a Roman port, but is now about two miles from the edge of the lake of Geneva, the land between the port and the lake being entirely alluvium and must have been deposited during the last 1,000 years. By the same kind of deposition, lakes are constantly being filled up with fine sand and mud, and in the course of time become marshy lands and green meadows. In fact, lakes and cataracts may be looked upon as accidental in a river system, for in the course of time the former becomes filled and the latter worn away.

Deposits where rivers enter the sea.—In precisely the same way that sediment is deposited and a barrier raised where a river enters the still waters of a lake, a deposit occurs when a river enters a sea or ocean where there is little or no current —a *bar* is formed. This deposit slowly rises to the surface of the water and becomes a tract of marshy land which in time obstructs and divides the river, causing it to enter the sea by two or more mouths instead of one. The river, instead of receiving tributaries, as heretofore, breaks up into many branches, a few only of which enter the sea. The point where the river is divided, marks the place where the deposit begins. Year by year more sediment is deposited and mainly where the river discharges into the sea, so that there is a constant growing out of land into the gulf or bay into which the discharge takes place. A typical example of this kind of formation is afforded by the Nile. At one time, this river must have discharged itself into the Mediterranean at Cairo, which is now, however, a hundred miles from the coast. The deposit from the two main branches has formed a triangular area of land which has filled up the gulf into which the discharge formerly took place. The distance between the two mouths of the Nile at Rosetta

and Damietta is 90 miles. There are many other mouths, however (Fig. 190), and the whole sea front between them is about 200 miles.

This triangular area of land which accumulates at the mouth of rivers is called a delta, because of its resemblance to the Greek letter Delta (Δ). The point where the deposit begins is called the head of the delta. The head of the delta of the Ganges is 200 miles from the sea, and the area of the delta is about 8,000 square miles; these facts indicate that it is a very

Fig. 190. The Delta of the Nile.

old formation. According to Lyell, borings in the Nile delta show that sand and alluvium continue to the depth of 120 feet below the surface, and then beds of gravel, pebbles, and other rocks occur, and at Calcutta, a boring of nearly 500 feet has been made without reaching the bottom of the alluvial deposit, consisting of sand, clay, gravel, and some layers of vegetation. The delta of the Brahmaputra river joins that of the Ganges, and there is a distance of about 200 miles along the sea coast between the mouths of the main branches of these rivers.

In the case of the Mississippi, the delta has long filled up the bay where the deposit first began, and long tongues of land are now being sent out far into the Gulf of Mexico. The increase of the delta of the Po is so considerable that Adria, which was once a port on this river, is now 14 miles from the mouth.

The conditions favourable to the formation of a Delta at the mouth of a river are :—

(1.) The water into which the river enters must be free from currents and great tidal action.
(2.) The velocity of the river must not be sufficient to carry it far out to sea.
(3.) A sheltered coast.

In other words, when the material is brought down quicker than it is carried away, a delta is formed. Where there is a great scour an estuary is produced. These facts explain why deltas are common in land-locked seas, as the Mediterranean and the Gulf of Mexico, where there is little tidal effect. Such a river as the Amazon forms no delta, although it must deposit a considerable amount of matter in the sea. The solid matter is carried so far out into the sea by the lighter fresh water that no sediment occurs at the river's mouth. It is said that the waters of this river can be distinguished 300 miles from its mouth on account of the suspended matter.

The action of internal forces in modifying the earth's crust is very great. There is reason to believe that there have always been about the same relative quantities of land and water as now exist, and since it has been shown that all land above sea-level would be washed away by river action in 3,000,000 years, some internal forces must be in action to preserve the ratio. We have already alluded to some effects of these forces. They are the slow movements of upheaval and depression, volcanic eruptions, earthquakes, and the evidence of subsidence afforded by coral reefs. To sum up then, we have two opposing sets of forces, one consisting of internal forces tending to raise portions of the earth's crust, the other being represented by external forces (denudation) and internal forces producing subsidence. The fact that the amount of land above sea-level remains practically constant shows that the work done by one set of forces is equal to that done by the other; hence we

are led to conclude that although the external forces producing changes in the crust are numerous and powerful the work done by internal forces is far greater.

QUESTIONS ON CHAPTER XX.

1. Explain the mechanical action of water, when frozen, in affecting the disintegration of rocks. (1888.)

2. Explain how glaciers and rivers respectively carry materials from high grounds to lower ones. (1887.)

3. Explain the action of frost in breaking up rock masses. Where does this kind of action go on most rapidly? (1886.)

4. What are deltas, and how are they formed? (1885.)

5. How can you prove that the waters of a river remove materials in a state of solution from the land, and how can the quantity of materials so removed be estimated? (1883.)

6. Describe the phenomena known as *roches moutonnées*, and explain how they are formed. (1880.)

7. State what rock constituents are carried by rivers to the sea in suspension and solution respectively, and describe what becomes of these materials when they reach the sea. (1879.)

8. What are moraines? Name the different kinds, and describe the manner in which they are formed. (1879.)

9. The River Rhone enters the Lake of Geneva as a muddy stream and leaves it as a perfectly clear one. State the source whence the sediment carried by the stream is derived, and what becomes of it. Explain the changes which are being produced in the physical features of the country by the removal and re-deposition of the material carried by the river.

CHAPTER XXI.

TERRESTRIAL MAGNETISM AND ELECTRICITY.

Natural Magnets.—A valuable iron ore having the composition Fe_3O_4, and known as magnetic oxide of iron, is found in large quantities in Scandinavia, the United States, and other places. It contains 72 per cent. of iron, and 28 per cent. of oxygen, and has a specific gravity from 4 to 5. The most remarkable property of this substance is that it attracts iron and a few other substances, and if a specimen be suspended in a stirrup so as to be free to move in a horizontal plane, it will set itself in a north and south direction. (Fig. 191.)

Fig. 191.
A piece of Lodestone suspended in a stirrup.

The ancients discovered this ore in Magnesia, a division of Asia Minor, near Smyrna, and named it *Magnes* stone, just as Portland stone is called by that name because it is found at Portland, and from this term the word *magnet* has been derived, and is applied to bodies possessing the attractive and directive properties of the natural ore. On account of the property of setting itself in a fixed direction the magnet-stone is called a 'lodestone,' or leading stone, from the Saxon word *laedean*, to lead.

Artificial Magnets.—When an ordinary knitting needle is dipped in iron filings it does not attract them. Neither will the needle set in a definite direction if freely suspended. But when the needle is drawn three or four times from end to end along a lodestone it acquires the property of attracting iron, and, if free to move, sets itself just as the lodestone does. And if one end of this needle be rubbed along another needle the new properties will be similarly imparted to the latter. A magnet has in fact been made in each case, and we express what has been done to the needles by saying that they have been *magnetised*. Bodies, *like these*, which have their magnetic properties given to them *artificially* are termed *artificial magnets*, as opposed to *natural*

magnets like lodestone. It must be at once understood, however, that artificial magnets, such as the common horseshoe magnet of schoolboys, are not usually made by rubbing pieces of iron or steel with lodestone, but by other far more powerful methods.

Poles of a Magnet.—A magnetised rod of iron or knitting needle dipped into iron filings and lifted out will be found to have filings collected in tufts near the two ends, very few, if any, adhering to the middle of the magnet. The quantity of iron filings picked up may be taken as a measure of the attractive force at the surface of the magnet, and the points where this force has its highest value are called the *poles*. A line drawn round a magnet midway between the two poles is known as the *neutral line*, and the *magnetic axis* is a line joining the poles. All magnets, natural or artificial, have two or more poles. It might be supposed that by breaking a properly magnetised knitting needle in halves two magnets, each having a single pole, would be obtained, but this is not so, for each of the pieces becomes a magnet having two poles, and this occurs however far the subdivision may be carried. A magnet free to move in a horizontal plane—a condition obtained by floating it on a piece of wood in water, by suspending it in a stirrup supported by a fine thread, or by balancing it on a pivot—assumes a direction which is nearly true north and south. (Fig. 192.) The end which points northwards is termed the north pole or north-seeking pole, and the one directed towards the south, the south pole, or south-seeking pole.

Fig. 192.
A Compass Needle balanced upon a vertical pivot *a b*.

Action of Magnets upon each other.—If the north pole of one magnet be brought near to the south pole of another magnet the two will be attracted, but if the north pole be presented to the north pole of a suspended magnet the latter will be repelled or driven away. In like manner a south pole attracts

the north pole of a magnet, and repels the south pole. Hence the law of this attraction and repulsion is 'like poles repel each other, but unlike poles attract each other.'

Difference between Magnets and Magnetic Substances.—A magnetic substance is one that is attracted by a magnet in all its parts. Thus, any part of a piece of soft iron is attracted by either pole of a magnet. But we have seen that a magnet is attracted by one end of a magnet and repelled by the other, and it is this latter circumstance that constitutes the difference between the two. Iron, steel, lodestone, nickel, and cobalt are magnetic substances. Oxygen is strongly magnetic. Prof. Dewar recently placed some of the liquefied gas in a rock-salt cup beneath the poles of a strong electro-magnet, and the liquid jumped up to the poles and clung there until it had evaporated. Nearly all substances are affected by a very strong magnet, the majority of them being not attracted but repelled. Bismuth is the metal which is most strongly repelled, but the comparative feebleness of the force may be gathered from the fact that, taking the attractive force of iron as 1,000,000, the force of repulsion exerted between Bismuth and a magnet is represented by $23\frac{1}{2}$.

Screening from Magnetic Action.—A magnet wrapped in a piece of paper will still pick up iron tacks or filings, although not in contact with them. Again, when a magnetic needle is placed under a glass or separated from a magnet by a thick piece of wood, the magnetic power is not screened off in the faintest, for the needle will be repelled or attracted by the magnet just the same as if no substance intervened. The only way to screen a body from magnetic influence is to place it in a vessel made of soft iron.

Magnetic Induction.—If one end of a piece of soft iron be held near to, but not touching, a strong magnet, the other end will pick up iron filings or iron tacks in the same manner as the magnet itself. The iron is said to be magnetised by *induction*. Take the magnet away and the soft iron loses its magnetic properties, and will not attract the filings or tacks. We see, therefore, that soft iron is easily magnetised but soon loses its magnetism. When a body has become magnetised by induction in this manner the end of it nearer to the inducing magnet has a pole of an opposite kind, and the end further away one of the same kind as the pole of the magnet causing the action. This can be proved by holding a magnet and a piece of soft iron in a straight line and testing the polarity of the end most removed from the inducing

pole. (Fig. 193.) Several iron tacks can be suspended in a chain from a magnet (Fig. 194) on account of the fact that the one touching the magnet has a like pole induced in its further end and an unlike pole in its nearer end; this tack similarly holds up

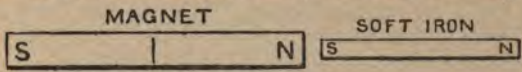


Fig. 193. Magnetic Induction.

the next by inducing a like pole in the far end of it and an unlike pole in the near end, and so the induction goes on down the series, until, when no more tacks can be supported, we find that the far end of the last has a pole of the same kind as the one from which the magnetic chain is suspended. Steel cannot be easily magnetised, but when it does become possessed of magnetic properties it keeps them. The behaviour of soft iron and steel with regard to magnetic induction reminds one of the saying, 'That which is easily gained is lightly prized.' Iron easily becomes a magnet and as easily loses its properties. Steel, on the other hand, is magnetised with difficulty, but permanently retains the properties imparted to it. We thus get 'temporary' and 'permanent' magnets, the former made of soft iron, the latter of steel.

Fig. 194. Magnetic Chain.

Lines of Force or Induction are defined as curves such that at any point they indicate the direction in which a north pole placed at that point would tend to move. If a magnetic pole be placed under a sheet of glass, iron filings sifted over the glass will be found to arrange themselves in radial lines, as in Fig. 195. Each particle becomes magnetised by induction, as explained in the preceding paragraph, and attracts the opposite induced pole of another particle, and so a number of radiating lines, indicating the

Fig. 195. Arrangement of iron filings on a piece of card resting on the north or south pole of a magnet.

direction of the lines of force or induction, are produced. The lines of force about the poles of a horseshoe magnet are shown in Fig. 196.

Fig. 196. Arrangement of iron filings on a piece of card placed upon the ends of a horseshoe magnet.

How to find the Cardinal Points.—In our hemisphere the shortest shadow of the sun on any day points to the true north. Or the line bisecting the positions of shadows of equal length before and after noon also points true north (see p. 105). In the evening if the stars are visible, the Pole Star or North Star enables the true north to be determined (see p. 113). We have seen that a magnetic needle sets itself in a direction which is approximately true north and south, hence, if we know how much its direction differs from the true north and south, we have a means of finding the latter even when the sun has set and the stars are hid by clouds. When the north point is known, the other cardinal points, south, east, and west, can easily be determined by construction. Thus the extremities of a line bisecting the north and south line at right angles are respectively the east and west points. And if the four right angles thus formed be bisected, the north-east, south-east, south-west and north-west points are obtained, and so on for other points of the compass.

Magnetic declination or variation is the angle between the geographical meridian and a vertical plane passing

through the axis of a magnet which is allowed to swing freely in a horizontal plane.—In London the north pole of a magnetic needle comes to rest pointing in a direction which is about 17° to the west of the true north. (Fig. 197.) This is, therefore, the present declination or variation at London. The declination differs at different places, *e.g.*, it is about 20° west of north at Liverpool, and 21° west at Glasgow, and at some places the magnetic and geographical meridians coincide, so the declination there is 0°. Lines connecting those places on the earth at which the declination is the same are called *isogonic* lines, the line along which there is no variation being termed the *agonic* line. Fig. 198 is a chart of the world on which some of these lines have been drawn. It will be seen that they converge towards two poles in the northern and southern hemispheres.

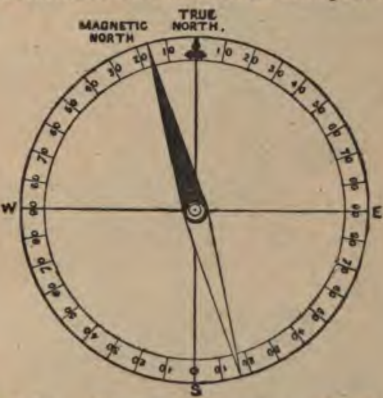
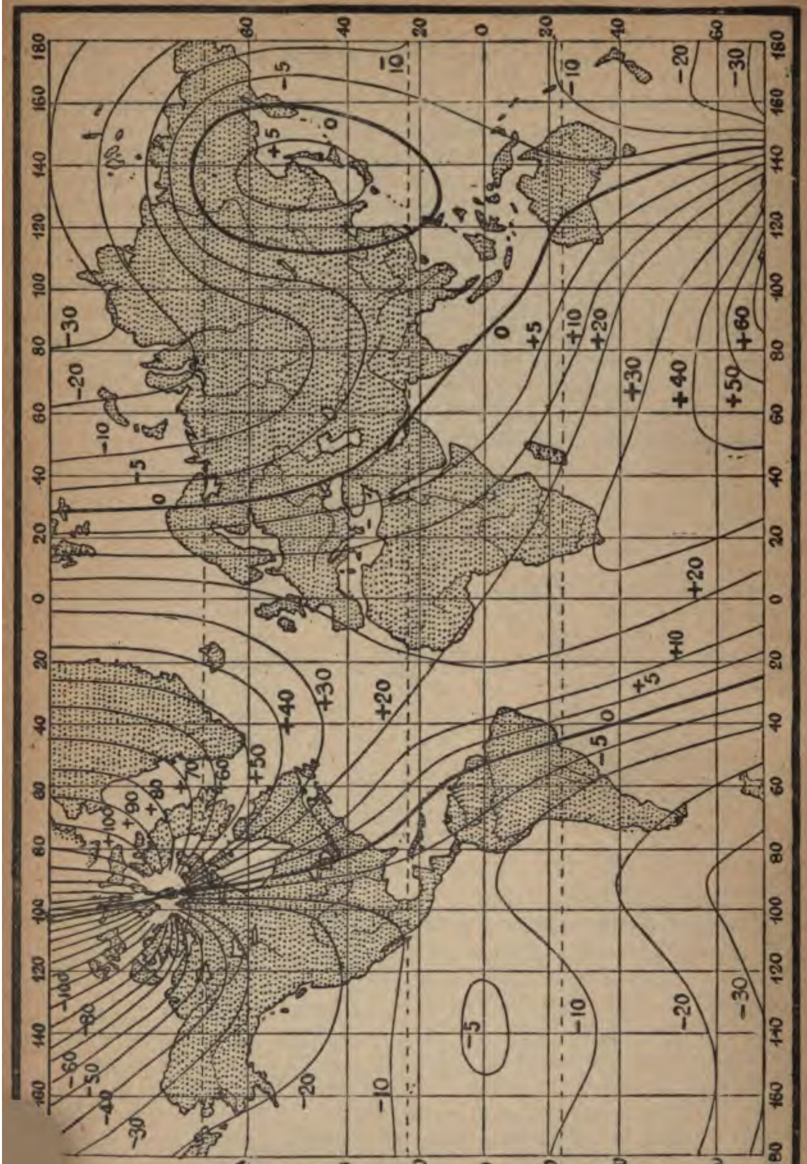


Fig. 197. Magnetic Declination at London.

Magnetic inclination is the angle which a magnetic needle free to move in a vertical plane makes with the horizontal when placed in the magnetic meridian.—So far we have only dealt with magnetic needles which were free to move in a horizontal plane. But, if a fine steel pin be fixed through the exact centre of such a needle and supported horizontally so that movement can only take place in a vertical plane, it will be found that the needle will dip down from the horizontal, the *north* pole pointing towards the earth in our latitudes. That this dipping is not due to want of balance can be proved by demagnetising the needle and making the other end a north pole,



198. Isogonic Lines, or lines connecting places having the same magnetic declination : + = Declination West ; — = Declination East.

when *it* will dip downwards. An instrument or 'dip-circle' for finding the angle of dip or inclination at any place is shown in Fig. 199. It is necessary that the needle should oscillate in the magnetic meridian. To obtain this desideratum the vertical circle is rotated on the horizontal base until the needle comes to rest in a vertical position, that is, until its extremities point to 90°. When this is the case, the needle is at right angles to the magnetic meridian, so that by rotating the vertical circle through 90° on the horizontal one the needle is accurately placed in the meridian and comes to rest at an angle (the angle of dip) which

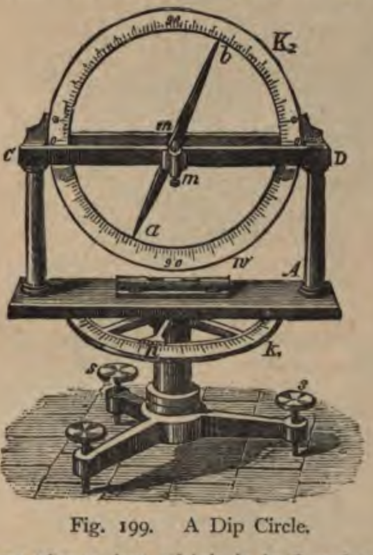


Fig. 199. A Dip Circle.

varies at different places, but which is in London at the present time about 67° below the horizontal. *Isoclinic* lines, or lines of equal dip, connect places where the dip is the same, that is to say, if a dipping needle were carried along a line of this character it should remain at the same angle throughout the journey. The line where there is no dip, that is, along which a dipping needle remains horizontal, is termed the magnetic equator or *aclinic* line. It will be seen from Fig. 200 that this line only coincides with the geographical equator at four points. At the magnetic poles a dipping needle comes to rest vertically.

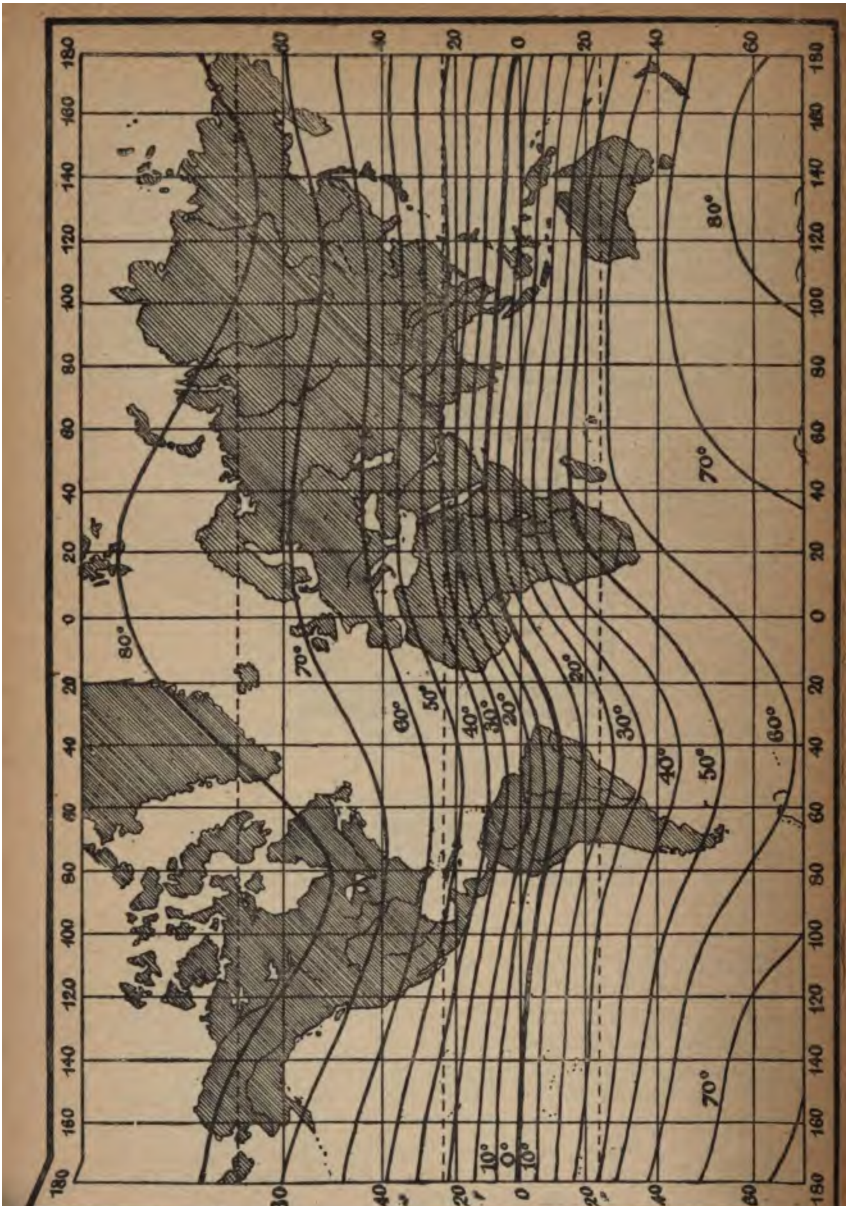


Fig. 200. Isoclinic Lines, or lines connecting places at which the magnetic inclinatio
is the same. Above the magnetic equator the north pole dips; below it
south pole.

The magnetic intensity at any place is the total magnetic force exerted on a needle placed there.—In the preceding paragraph we stated that a dipping needle comes to rest vertically when free to move in a plane at right angles to the magnetic meridian, and only indicates the proper dip when in the meridian. We may consider the needle to be acted upon by two forces, one tending to pull it horizontal, the other tending to make it stand vertical. In accordance with the law of the composition of forces previously explained (p. 17), the needle, in the latter case, takes up a position between the directions of the two forces. But when the needle is out of the magnetic meridian the horizontal force pulls it only against the pivots, and when at right angles to the meridian the effect of the horizontal force is entirely lost, and so the needle sets vertically. In like manner an ordinary horizontal compass needle is affected only by the horizontal component, for the vertical one merely pulls it down upon the pivot on which it turns. A dipping needle in the magnetic meridian, therefore, indicates the *direction* of the total magnetic force exerted upon it. The relation of the horizontal, vertical, and total force to each other will be understood from Fig. 201. The intensities of these forces are expressed in the same manner as other forces. They are most conveniently found by measuring the horizontal force and the angle of dip at any place, and from the data thus obtained the total force or magnetic intensity can be calculated. These three facts contain all the information about the magnetic action of the earth at any place, and are therefore termed the *magnetic elements*.

Fig. 201.
Relation of the horizontal to the vertical force.

Secular variations of terrestrial magnetism are those which take ages for their completion. Thus, in London in 1580 A.D. the declination was 11° E. of N.; in 1659 the needle pointed due north; it then slowly increased its declination westward until in 1818 the value 24° 41′ was reached, and since then it has been moving back towards the north, the declination at Greenwich Observatory in 1892 being 17° 20′ W. The inclination changes in like manner at all places. In London in 1576 it was 71° 50′, a maximum of 74° 42′ was reached in 1720, and since

then the angle has been decreasing, its value at Greenwich Observatory in 1892 being 67° 21′.

Annual and daily variations of terrestrial magnetism also occur. From April to July the declination suffers a slight decrease, that is, it moves eastward, and then slowly increases again for the remainder of the year. The inclination also varies, being about 0·27′ lower than the mean from April to September, and about the same amount higher than the mean from September to April. The magnetic needle changes its position slightly during the day. At 10 a.m. it occupies its mean position. It then moves westward and reaches a maximum of 6′ or 7′ to the west of the mean position about one o'clock. The declination afterwards decreases until the mean position is regained about 7 p.m. A slight movement to the east occurs during the night, and a maximum of about 4° E. is reached about eight o'clock in the morning. From 8 a.m. to 10 a.m. the needle swings back to the mean position. The inclination has also a diurnal variation, reaching a maximum about 8 a.m. and a minimum about 3 p.m. Both the annual and diurnal variations can only be detected by means of very sensitive instruments.

Irregular variations cause the magnetic needle to move in a sort of zigzag fashion instead of steadily progressing towards the west or east according to the time of day. These irregular disturbances are known as 'magnetic storms,' and sometimes cause the needle to vary a couple of degrees from its mean course. The aurora borealis appears to be intimately connected with magnetic storms, for magnetic irregularities invariably accompany the appearance of this phenomenon, and the luminous beams and columns have very often a direction parallel to that of a dipping needle at the place where they are observed. Earthquakes and volcanic eruptions have also a marked effect upon the course of the needle. It has been shown that periods of marked auroral displays succeed each other at an average interval of about ten or eleven years, the period of maximum frequency coinciding with the period when the black spots on the sun's surface are most numerous.

The mariner's compass is used to find the north point at sea. It consists of a magnetic needle attached below a circular card divided as in Fig. 202, and suspended on a pivot. The north and south points on the card should be exactly over the magnetic axis of the needle. Hence the north and south line of the card always lies in the magnetic meridian of the place of observation,

although the needle which causes it to take up this direction is not visible. The basin or compass-box containing the pivot on which the needle and card rest is supported on *gimbals*, so that the compass-box and card always swing horizontal however great the rolling of the ship may be. Inside the compass-box is marked a vertical black line called the *lubber-line*. This line is in the axis of the ship and indicates the direction of the bow. The point of the compass at the lubber-line at any moment shows the direction in which the ship is moving. If, therefore, the helmsman desires to steer north-west he turns the helm until the point N.W. comes to the lubber-line. In a land compass the magnet is pivoted above the divided card, so although it is always directed north and south any point of the card may be under the north pole. It is a common mistake among uneducated people to think that the north point of the card should always be under the north pole of the needle. This, of course, cannot be the case. To use a land compass properly the box should be turned until the north point is under the north pole, and then the required direction can be read off. To get the true north from the magnetic north, whether on sea or land, it is necessary to know the magnetic declination or variation at the place of observation. All ships on long voyages carry charts showing the declination at the regions they will visit, and this has to be added to or subtracted from the true course of the ship in order to obtain the course which has to be followed by the 'man at the wheel.'

Fig. 202. A Compass Card.

The Earth behaves like a great magnet in its effects upon magnetic needles. In the first place, it attracts a needle supported on either a vertical or horizontal axis. The terrestrial lines of force indicated by isogonic lines converge to poles in the northern and southern hemispheres. And similar regions of great magnetic intensity are exhibited by the arrangement of isoclinic lines. A needle supported on a horizontal axis comes

to rest in a horizontal position at the magnetic equator and the north-seeking pole gradually dips downwards as it is carried northwards, until at some point near the pole the needle stands vertical. This point in the northern hemisphere is a little to the north of Hudson's Bay, about 1,000 miles from the north geographical pole, in lat. 70° N., long. 96° 43′ W. The south magnetic pole is probably situated about lat. 75° S. and long. 150° E., but its exact position has not yet been found by observation. Roughly speaking, therefore, the earth behaves as if a great magnet was inside it, with its south pole near the north pole of the earth, its north pole near the south pole of the earth, and its central line nearly coinciding with the earth's equator. The magnet must not for a moment be supposed really to exist, but must merely be looked upon as a convenient fiction which will explain the main phenomena of terrestrial magnetism; for the direction taken by magnetic needles at any particular district is considerably affected by the character of the rocks in the neighbourhood, both below and at the surface.

Elementary notions with regard to statical electricity.—When two different substances are rubbed together each of them acquires a state such that they are able to attract light bodies towards them. If a piece of glass be rubbed with a bit of silk, the former will pick up bran, feathers, or any similar light materials. And, by proper means, the silk can be shown to behave in a similar manner. A rod of ebonite or sealing-wax rubbed with catskin or flannel also acquires attractive properties. A rubbed rod of glass attracts a rubbed rod of ebonite or sealing-wax supported in a stirrup as in Fig. 203, or balanced on a watch-glass, but repels a similarly rubbed rod of glass. In like manner, rubbed sealing-wax or ebonite repels bodies in the same electrified state as itself, but attracts rubbed glass. We therefore have two kinds of frictional electricity, respectively represented by rubbed glass and rubbed ebonite, and they conform to a law similar to that possessed by magnets, viz., 'like electrified bodies repel each other and unlike electrified bodies attract each other.' These two electrified states are called positive and negative, or briefly, + and −, and one can never be produced without the other. Thus, glass becomes positively electrified and silk negatively

Fig. 203.
Method of suspending an electrified rod.

electrified when they are rubbed together. Ebonite becomes negatively electrified and flannel positively electrified when rubbed together. The substances in the following list are so arranged that if two of them are rubbed together the higher becomes $+^{ly}$ electrified and the lower $-^{ly}$ electrified.

1. Fur.	4. Resin.	7. Cotton.	10. Ebonite.
2. Flannel.	5. Metals.	8. Silk.	11. Caoutchouc.
3. Wood.	6. Glass.	9. Sulphur.	12. Guncotton.

Some bodies conduct, or allow electricity to pass along them, more easily than others, and are said to be good conductors. Under ordinary circumstances the electricity developed in silk rubbed against glass does not remain in the former, but is conducted away through the body of the operator to the earth, whereas the glass retains its electrification. It is on this account that the silk or flannel rubber, as the case may be, does not exhibit the electricity with which it has been endowed by the friction. The following is a list of good, imperfect, and bad conductors or insulators of frictional or statical electricity.

Good Conductors.	Imperfect Conductors.	Bad Conductors.
Metals.	Cotton.	Caoutchouc.
Gas, coke, and charcoal.	Wood.	Ebonite.
Acids and metallic salts.	Fats and oils.	Silk.
Water.		Shellac.
		Glass.
		Paraffin.
		Dry Air.

It is perhaps better to speak of the resistance of a body to the passage of electricity than of the conductivity, because even the best conductors offer a certain amount of resistance.

An electrified body induces an equal amount of electricity on bodies around it just as a magnet induces magnetism in soft iron. When the inducing body loses its electricity those electrified by induction return to their normal state. This action at a distance is well illustrated by means of an instrument termed an electroscope, consisting of two gold leaves fastened on one end of a piece of wire supported on an insulator, and surmounted at the other

Fig. 204.
An Electroscope.

end by a metal disc or ball. (Fig. 204.) A rubbed glass rod brought near to the top of the instrument causes the gold leaves to separate and stand out in the form of an inverted V, owing to their becoming possessed of like electricity and repelling each other. And it can be easily proved that the electricity in the leaves is of the same kind as that of the inducing body, and that on the disc is of the opposite kind. As soon as the excited rod is taken away the leaves again fall together.

Electrical Machines.—The simplest kind of electrical machine consists of a glass plate or cylinder, which is rubbed against silk or leather by turning a handle. One in which a cylinder is used is shown in Fig. 205. The positive electricity developed on the glass is collected by means of the figured metal

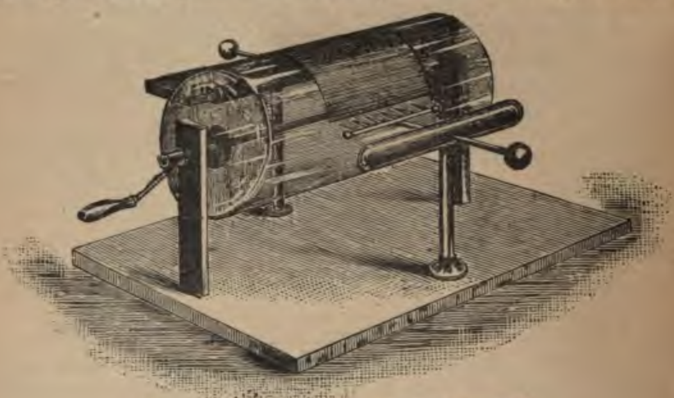


Fig. 205. A Cylinder Electrical Machine.

cylinder with rounded ends known as the 'prime conductor.' This is supported on an insulating pillar and armed with spikes on the side facing the glass. The glass becomes positively electrified by friction against the rubber, and in passing the metal cylinder electrifies it by induction, the unlike electricity being attracted to the spikes, whilst the like electricity is driven to the further side. The former is dissipated into the air by the points, and by this loss the prime conductor gradually becomes charged with positive electricity. When such a machine is in action a bright spark will pass with a snapping noise from the *prime conductor* to anything held near it. The luminosity of the

spark is due to the heating to incandescence of the air through which it passes. When the spark is made to pass through hydrogen a red luminosity is the result, and carbon dioxide is rendered green. The spark passes more easily when the gaseous media are rarefied.

Atmospheric Electricity.—The first observers of the electric spark must have noticed its resemblance to lightning. The identity of the electricity of a thunder-cloud with that produced by means of an electrical machine was proved by Franklin in 1752. He sent up a kite attached to a piece of string at the end of which a key was tied. The key was fastened to a strip of silk which could be held in one hand or tied up to a post. No sparks could at first be obtained from the key, but after a fall of rain had wetted the string, and so improved its conductivity, sparks could be drawn from it in rapid succession, just as they can be taken from the prime conductor of an electrical machine in action. The air is always charged with either positive or negative electricity, and the charge increases in power the higher we ascend. During a thunder-storm, however, the quantity and kind of electricity varies considerably.

The origin of Atmospheric Electricity is very probably the friction of particles of water-vapour against surfaces of rock and ice on the earth, and against the latter in the higher regions of the atmosphere. Electricity is certainly developed by evaporation, and so is continually being produced. And it can be shown that when several minute particles of water-vapour in a cloud coalesce into single drops, the electrical condition of the cloud of which the drops form part is thereby enormously increased. As the drops increase in size the cloud becomes darker and its electrical condition is increased. The cloud finally loses its electricity by discharges of lightning.

Lightning is a visible effect caused by electric discharges between clouds or between clouds and the earth.— Three kinds of lightning are usually distinguished, viz., *forked*, or crooked lightning, *sheet*, heat, or summer lightning, and *ball* or globular lightning. The first is nothing more than a long electric spark, represented in miniature by a spark from an electrical machine. Its length is often over a mile and sometimes four or five miles. The duration of the flash is only about one millionth part of a second. The *light and heat* developed during a lightning discharge is due to

the heating to incandescence of the oxygen, nitrogen, and other gases through which the spark passes, and also the volatilising of some of the meteoritic particles in the atmosphere. The irregular form is due to the different resistances offered by different portions of air to the passage of the discharge. A reproduction of an electric discharge of this character is shown in Fig. 206. The photographs that have been taken of lightning discharges show that the zig-zag dovetail form represented by artists does not exist. The flashes are generally of a more or less

Fig. 206. A Lightning Discharge. (*From a Photograph.*)

sinuous character, but are never zig-zag. Sheet-lightning is the glow which frequently illuminates the horizon in summer. It is, in all probability, the reflection of flashes of forked lightning occurring below the horizon, and not directly visible. Ball-lightning is a rare phenomenon which has not as yet been imitated by discharges of electrical machines. A ball of luminous matter proceeds from the region of the discharge and after travelling slowly through the air or along the earth for a few seconds, it explodes.

Damage by Lightning.—Some effects produced by ball and forked lightning striking a building are described in the ollowing extract from observations made at Pike's Peak, in olorado, U.S.A., at a height of 14,134 feet above sea-level. 5.40 p.m. a bolt of lightning went through the arrester with

the report of a rifle, throwing a ball of fire across the room against the stove and its sheathing. At 6.35 p.m. the lightning struck the wire and building at the north end where the wires come through the window, with a crash equal to any 40-pounder. It burned every one of the wires coming in at the window into small pieces, throwing them with great force in every direction, and filling the room with smoke from the burning gutta-percha insulation. The window sash was splintered on the outside, one pane of glass broken and another coated with melted copper. The anemometer wires were also burnt up and the dial burnt and blown to pieces.' One reason why it is dangerous to stand under a tree during a thunderstorm is that the body is a better conductor of electricity than the wood and so the discharge prefers to pass through it to the earth.

Thunder is the noise heard after a flash of lightning has occurred. It is caused by a rapid in-rush of air-particles to fill the partial vacuum formed by the lightning discharge heating the air in its track. When the flash is short and the sounds reach the ear at the same time a *thunder-clap* is heard. In long and zigzag flashes the sounds produced at different points of the path have different distances to travel before they reach the ear, and their arrival one after another causes a *thunder peal* to be heard. Rolling or rumbling are produced by the echoes of thunder among the clouds and between the clouds and the earth. A flash of lightning is seen practically at the same instant as the discharge occurs, for light travels at the enormous rate of 186,000 miles in a second. The interval that elapses between the seeing of lightning and hearing of thunder is variable. Sometimes a thunder-clap is heard a second or so after the flash has been seen, and at other times several seconds may pass. The cause of this interval is due to the difference between the velocity of light and that of sound in air, the latter being approximately 1,100 feet per second. If thunder is heard a second after a lightning discharge, it can be said that the distance of the thunder cloud is about 1,100 feet. If the interval that elapses between the occurrence of the two phenomena be two seconds the cloud is about 2,200 feet distant, and so on for any other interval. And, since danger from lightning generally decreases as the distance of the discharge from an observer increases, nervous individuals may calm their apprehensions when they find the interval between a lightning flash and thunder getting longer and longer.

Lightning conductors are used for the purpose of preventing damage by lightning. The most perfect way to protect a building would be to enclose it in a metallic wire cage, but this is not practicable. Prof. Lodge lays down the following conditions which should be fulfilled by lightning conductors:—

(1) All parts of a lightning conductor should be made of one and the same metal, avoiding joints as far as possible, and with as few sharp bends or corners as possible.

(2) The use of copper for lightning rods is a needless extravagance. Iron is by far the best metal. Ribbon has a slight advantage over round rod; but ordinary galvanised iron telegraph wire is good enough.

(3) The conductor should terminate not merely at the highest point of a building, but be carried to all high points. It is, however, not wise to erect very tall pointed rods projecting several feet above the roof.

(4) A good deep earth should be provided, independent of gas or water mains.

(5) If in any part the conductor goes near a gas or water pipe, it is better to connect them metallically than to leave them apart.

(6) In ordinary buildings the conductor should be insulated away from the walls, so as to lessen the liability of lateral discharge to metal stoves and things inside the house.

(7) Connect all external metal work—zinc spouts, iron crest ornaments and the like—to each other and to earth, but *not* to the lightning conductor.

(8) The cheapest way of protecting an ordinary house is to run common galvanised iron telegraph wire up all the corners, along the ridges and eaves, and over all the chimneys, taking them down to the earth in several places, and at each place burying a load of coke.

(9) Over the top of tall chimneys it is well to take a loop or arch of the lightning conductor, made of any stout and durable metal.

Inductive action of electrified clouds.—The tops ships' masts, of trees, and other objects are sometimes seen to w. This luminosity is known as *St. Elmo's fire.* It is caused he *slow discharge* of electricity and can be imitated by sticking 'nted *rod of* metal in the prime conductor of an electrical

machine in action. The spikes facing the glass cylinder, described on page 392, become tipped with a similar glow, which can easily be seen in a darkened room. In this case, the electrified glass is the inducing agent. In the case of the masts of ships, etc., electrified clouds cause the discharge. A striking manifestation of this character has been noticed on Pike's Peak, during the passage of electrified clouds over the summit. When an observer raised his hands and spread his fingers, 'each of them became tipped with one or more cones of light, nearly three inches in length. The flames issued from his fingers with a rushing noise, similar to that produced by blowing against the end of the finger when placed lightly against the lips, and accompanied by a cracking sound . . . . The wrist-band of his woollen shirt, as soon as it became dampened, formed a fiery ring around his arm, while his moustache was electrified so as to make a veritable lantern of his face.' This inductive action may produce serious effects for the following reason. Suppose an extensive electrified cloud to lie over the earth, one part being over a person and another over an elevated point, such as a church spire or hill-top. The cloud electrifies the objects on the earth by induction, and therefore the person may unconsciously have in his head electricity unlike that of the cloud, whilst his feet have the opposite electrification. When a discharge takes place between the cloud and some prominent object on the earth or between it and another cloud, all inductive action on the individual instantly ceases and this abrupt neutralisation produces a more or less severe shock, known as the *return-shock* or *back-stroke*.

The Aurora Polaris, or Polar Light is a beautiful phenomenon frequently seen in high latitudes and termed *aurora borealis* or *aurora australis* according as it appears in the neighbourhood of the north or south poles respectively. No adequate description can be given of the appearance of aurorae. Generally a number of luminous beams, rays, or streamers shoot up from the horizon, and converge to a point near the zenith. The convergence is really an effect of perspective for the streamers are parallel to each other. It was proved as early as 1793 that the luminous beams have their lengths in the directions of the dipping-needle at the point over which they appear. Hence a theodolite adjusted so as to point in the direction towards which the beams converge, is parallel to a dipping needle fixed in the magnetic meridian at the place of observation. 'Th

well remembered aurora of September 2nd, 1859, formed a belt of light encircling the northern hemisphere, extending southward in North America to latitude $22\frac{1}{2}°$, and reaching to an unknown distance on the north; and it pervaded the entire interval between the elevation of 50 and 500 miles above the earth's surface. This illumination consisted chiefly of luminous beams or columns, everywhere nearly parallel to the direction of a magnetic needle when freely suspended; that is, in the United States these beams were nearly vertical—their upper extremities

Fig. 207. Aurora Borealis, observed in Alaska, 27th December, 1865.

being inclined southward at angles varying from 15° to 30°. These beams were, therefore, about 500 miles in length; and their diameters varied from five to ten and twenty miles, and perhaps sometimes they were still greater.' Aurorae are also intimately connected with 'magnetic storms,' to such an extent in fact that one of these classes of phenomena is invariably accompanied by the other.

The colour of an aurora is often a greenish yellow, but *crimson and blue* and many other tints have been observed at

the same time. The cause of the luminosity is the discharge of electricity in rarefied air, whereby the gas is rendered incandescent. The appearance can be imitated in the laboratory by causing electric discharges to pass through vessels containing more or less rarefied air. The variations of colour may therefore result from the different heights at which the discharge occurs, the air decreasing in density as its distance from the earth's surface increases. Professor Lockyer has shown that a large part of the luminosity of aurorae is due to the heating and volatilising by means of the electric discharge of some of the constituents of the enormous number of meteoritic particles that exist in the atmosphere.

QUESTIONS ON CHAPTER XXI.

1. Does the mariner's compass point due north? If not, why not? (1888.)

2. What is the cause of the interval which elapses between a flash of lightning and the accompanying thunderclap? If this interval, in any particular case, were found to be eleven seconds, what inference would you draw from the fact? (1880.)

3. What is the cause of the noise heard during thunderstorms? (1879.)

4. What are the magnetic poles, and what do you know about their geographical position? (1878.)

5. In what direction does a magnetic needle in this country point, and why does it not everywhere assume a due north and south direction? (1877.)

6. What is the difference between magnets and magnetic substances, and between natural and artificial magnets?

7. What is the probable origin of atmospheric electricity?

8. What facts point to a connection between aurorae and terrestrial magnetism?

MODEL ANSWERS TO THE ELEMENTARY PHYSIOGRAPHY QUESTIONS

SET AT THE MAY EXAMINATION OF THE SCIENCE AND ART DEPARTMENT, 1891.

SERIES I.

1. (*a*) What chemical element is present both in air and water?

(*b*) State the chief properties of this elementary substance.

(*c*) What proportion of this element is contained in air and water respectively?

(*d*) In what condition does the element exist in air and water respectively?

(*a*) Oxygen.

(*b*) Oxygen has no colour, taste, or smell, and is an active supporter of combustion. Water dissolves about three per cent. of its volume of the gas at 15° C. Its specific gravity compared with air is 1·105. Under a pressure of 320 atmospheres and a temperature of —140°, oxygen is transformed to a sky-blue liquid.

(*c*) Air contains 23 per cent. of oxygen by weight and 20·8 per cent by volume. Water contains 88·8 per cent of oxygen by weight and 50 per cent. by volume. (The proportional composition of water may also be expressed by saying that 36 lbs. of water contains 32 lbs. of oxygen, and two pints of water contain one pint of oxygen, measured at the same temperature and pressure.)

(*d*) Oxygen exists uncombined in air, but in water it is chemically united to hydrogen—one atom of oxygen being joined to two atoms of hydrogen. ($H_2 + O = H_2O$.)

2. (*a*) State the principle on which the action of a mercurial barometer depends.

(*b*) Why is a water barometer longer than a mercurial barometer?

(*c*) What occupies the space above the mercurial column in the latter ament?

If a hole were to be bored through the glass above the column of ry what would happen?

(*a*) If two liquids, say mercury and water, are placed in the arms of a U-shaped tube, a short column of mercury will be found to balance a long column of water (Fig. 1). In like manner, the mercury

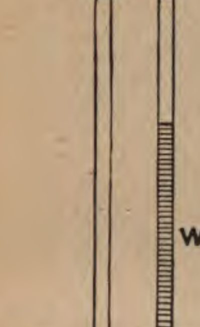


Fig. 1.

introduced into a tube, such as that illustrated by Fig. 2, balances a column of air extending upwards to the limits of the atmosphere. In an ordinary cistern barometer the pressure of the atmosphere on the surface of the mercury in the basin sustains the mercury in the tube; if the pressure decreases, the column shortens; if the pressure increases, the column stands higher.

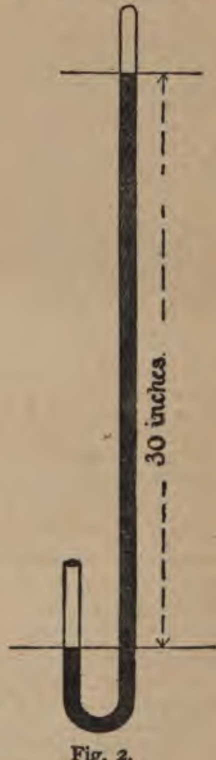


Fig. 2.

(*b*) A short column of mercury balances a long column of water, therefore mercury is heavier bulk for bulk than water; actually its specific gravity is 13·6. Hence a water barometer has to be 13·6 times longer than a mercurial one, because of this difference in specific gravity.

(*c*) The vapour of mercury.

(*d*) The mercury would fall down the tube to the level of that in the cistern.

3. (*a*) What is the source of the water that falls as rain?

(*b*) What becomes of it when it reaches the ground?

(*c*) How do we indicate the quantity of rain which falls upon a given place during a year?

(*a*) The water on the earth. Clouds are formed of water which has evaporated from the earth, and rain is produced by the condensation

of the water particles forming a cloud so as to form larger drops, which fall to the ground through the action of the force of gravity.

(*b*) Part sinks into the ground to form springs, part flows off the land at once into rivers, and another part returns to the atmosphere again by evaporation.

(*c*) Rainfall is measured by means of a rain-gauge, and is expressed as the thickness in inches of the fall if it were spread evenly over the surface of the land where it occurred. The mean annual rainfall of any place is determined by measuring the yearly rainfall for several years and finding the average.

4. (*a*) What is meant by a 'raised beach'?
(*b*) What do we learn from its existence?
(*c*) Name any place where raised beaches are found.

(*a*) A tract of land or a sea-beach that has been raised above sea-level. The evidences of such upheaval are various. Sometimes a line of cliffs above sea-level is found covered with the remains of barnacles and other marine organisms. Or caves worn out of cliffs by the action of the sea are found at a certain distance inland, because of the elevation of the land. In some cases piers and harbours are rendered useless by being elevated above the high-water mark.

(*b*) That land is subject to slow movements of upheaval. Sea-worn caves can only be formed at sea-level, and marine shells do not naturally occur in any quantity above the level of high-water. When, therefore, these are found above the level of the waves, it is concluded that the land containing them has been elevated.

(*c*) The West Coast of South America, Spitzbergen, and many parts of the coast of England, *e.g.*, Sandwich and Winchelsea.

SERIES II.

5. How are the light and heat produced?
(*a*) When a match is struck.
(*b*) When a candle burns.
(*c*) In a flash of lightning.

(*a*) An ordinary lucifer match contains phosphorus and potassium chlorate. These bodies will not combine with each other, or with the oxygen in the air, unless they are heated. In the case given, the chemical action which occurs is started by the heat produced by friction against a rough surface; afterwards, the heat given out as the above substances combine with each other is more than sufficient to carry on the combustion, of which light and heat is the result.

(*b*) Combustion occurs whenever chemical action is accompanied by the development of light and heat. When a candle burns the carbon and hydrogen in the tallow or wax combine with the oxygen in the air to form carbon-dioxide and water, and heat and light are evolved so long as such chemical action, or burning, or combustion goes on.

(*c*) The air and the particles of dust in it are rendered incandescent by the passage of the electric spark. The colour of lightning depends upon the rarefaction of the air through which the discharge passes. In the lower regions of the atmosphere it is white, but in higher regions, where the air is less dense, the discharge may have a violet hue.

6. How would you set out a north and south line?

(*a*) By the mariners' compass.

(*b*) By the sun.

(*c*) By a star.

(*a*) Draw a line in the direction of the north and south points of the compass. This line will indicate the magnetic and not the geographical meridian. To determine the true north and south, the magnetic variation at the place of observation must be found. At the present time the magnetic north at Greenwich is about 17° west of the true north.

(*b*) One method is to observe the shortest shadow of a fixed post on any day, and to draw a line in its direction. A better method is to mark the length and position of the shadow of a post some time before noon, and then to draw another line in the direction of the shadow having the same length after noon. The line bisecting the angle contained between these two lines points true north and south.

(*c*) By taking the direction of a telescope or a straight rod pointed to the pole star. But the pole star is $1\frac{1}{4}°$ distant from the celestial pole, and therefore it describes a circle, having a radius of $1\frac{1}{4}°$ round the true north point in the heavens. Hence, for an exact determination it is necessary to know in what part of the circle the pole star is at the time of observation.

7. What difference is observed in the place of the rising and setting of the sun (1) at different times of the year at any place in the British Isles? (2) at the summer solstices in different parts of the northern hemisphere?

(*a*) At the equinoxes (vernal and autumnal) the sun rises due east and sets due west all over the earth. When the arcs described by the sun in the heavens are increasing in size, that is, from winter to summer, our luminary rises and sets more and more north; as they decrease in size it is moving south. In London, at the summer solstice, the amplitude of the point on the horizon at which the sun rises is about 40° N. of E.; and the amplitude at sunset, 40° N. of W. At the winter solstice the amplitudes of rising and setting are 40° S. of E. and 40° S. of W. respectively.

(*b*) A the equator the sun rises due east and sets due west all the year round. In latitude 25° the amplitude of the sun at the solstices is about 26°; in latitude 50° its amplitude at the solstices is about $38\frac{1}{2}°$, the amplitudes increasing with the latitude.

8. State one experimental proof of the earth's rotation.

(An outline sketch of the gyroscope shown in Fig. 58, page 123, is sufficient with the following explanation.)

A is a heavy rimmed wheel in rapid rotation in the ring B, which is supported inside another ring, C, suspended by a thread D E, and capable of turning on the point F. As the earth rotates the microscope and scale are carried round in the opposite direction to that of the hands of a watch, in the northern hemisphere, and therefore the end of the pointer S appears to move in the same direction as watch hands.

MODEL ANSWERS TO QUESTIONS IN ELEMENTARY PHYSIOGRAPHY, 1892.

SERIES I.

1. (*a*) What is an oxide?

(*b*) Name two oxides which are always present in the atmosphere and give their composition.

(*c*) What is the most abundant oxide in the crust of the globe?

(*d*) State what you know concerning the composition and mode of occurrence of this oxide.

(*a*) An oxide is a compound formed by the union of oxygen with another element; that is, a binary compound having oxygen for one of its constituents.

(*b*) Carbon dioxide, or Carbonic acid, = CO_2; Water, or hydrogen monoxide, = H_2O.

(*c*) Silica, or oxide of silicon.

(*d*) Silica is composed of silicon and oxygen, and has the chemical formula SiO_2. It occurs *pure* in nature in the crystalline form as quartz and tridymite, and in the non-crystalline or amorphous form as opal. Many other minerals are mixtures of these varieties with each other and various impurities. Silica also occurs abundantly in combination with metallic oxides, forming silicates. The felspars and micas are examples of such groups of minerals.

2. (*a*) Why is the tube of a thermometer made with a narrow bore, while the bulb is large?

(*b*) Why is the top of a thermometer tube sealed up?

(*c*) Why is mercury the best liquid to use in a thermometer under ordinary circumstances?

(*d*) Under what circumstances is alcohol used instead of mercury?

(*a*) In order to make the thermometer sensitive to small variations of temperature: Let two bulbs be taken of exactly the same size, but having stems differing considerably in width. Fill each of the bulbs with mercury, and then place them together in hot water. The mercury expands the same amount in each bulb, but the indications on the stems will be very different. In the bulb with the wide stem the top of the mercury will have moved a short distance above its former position, but in the case of the bulb with the narrow stem the same increase of volume has been lengthened out, in consequence of the fine bore, so the top of the mercury will have moved a long distance.

(*b*) To prevent loss by evaporation: If the liquid in the thermometer were allowed to evaporate, the graduation of the instrument would soon be useless. By sealing up the end, dirt is also prevented from entering the thermometer.

(*c*) It remains liquid through a long range of temperature, viz: 40° F. to 660° F.

Its rate of expansion is practically constant.
It has a low specific heat.
It is a good conductor of heat.
It is easily seen against the glass.

(*d*) In thermometers required to indicate low temperatures: Mercury freezes when its temperature is lowered to 40° below zero (Fahrenheit); alcohol has never been frozen. Alcohol is also frequently used instead of mercury in common thermometers, on account of its cheapness.

3. State the origin of the following appearances about an active volcano.

(*a*) The clouds which collect above it.
(*b*) The glow seen above it at night.
(*c*) The flashes of lightning playing about the cloud.
(*d*) The sounds which are heard.

(*a*) The vapour of water forms almost the whole of the white cloud which hangs over a volcano in action. Water is one of the chief agents of volcanic outbursts. Its vapour, steam, accumulates at volcanic centres, and in time overcomes the pressure tending to prevent its escape. The cause of volcanic explosions is thus the expansion and escape of masses of high pressure water vapour, and the clouds referred to are caused by the condensation of this vapour.

(*b*) The glare of the molten lava in the crater of the volcano being reflected from the clouds above. Steam escaping from a locomotive can often be seen at night similarly illuminated by the light of the open furnace door.

(*c*) The friction of escaping particles of water-vapour, and dust against the sides of the crater, and against one another, develops a large quantity of electricity. Different parts of the clouds get differently electrified, and the electrical condition of some clouds differ from that of the adjacent surface of the earth. When the electrical tension is sufficiently high, sparks pass between two clouds, or between clouds and the earth, and by raising the air and dust particles to a state of incandescence, produce the phenomenon known as lightning.

(*d*) The thunder which accompanies the electrical discharges, explosions of steam, and the grinding together of large and small masses of rock inside and outside the crater.

4. If you ascended to the height of 3½ miles in a balloon, carrying a barometer and a thermometer, state—

(*a*) The indication which would be given by the barometer.
(*b*) Your explanation of this.
(*c*) The indication which would be given by the thermometer.

(*d*) Your explanation of this.

(*a*) The barometer would fall to 15 inches, that is, one-half the indication at sea level.

(*b*) The column of mercury or other liquid in a barometer balances a column of air of the same sectional area, extending to the limits of the earth's atmosphere. If the column of air is shortened by $3\frac{1}{2}$ miles by ascending into the atmosphere, the mercury in the barometer falls. Since air is elastic, the layers near the earth's surface are much denser than those higher up; hence, although the atmosphere probably extends to a height of 200 miles, one-half of it is left behind in ascending $3\frac{1}{2}$ miles.

(*c*) The fall of temperature would be about 1° Fahr. for every 300 feet of ascent, so if the temperature at the earth's surface were 60° Fahr., at a height of $3\frac{1}{2}$ miles (18,480 feet) it would be 1° Fahr., that is 31° Fahr., below the freezing point of water.

(*d*) The atmosphere derives its heat chiefly by radiation from the earth's surface, and not directly from the sun; air at a height of three-and-a half miles is thus further removed from the radiating source than that at sea level, and is consequently colder. The expansion of air in rising also causes the atmosphere at a high level to have a low temperature.

SERIES II.

5. Define force, energy, momentum, stress.

Force is any cause that alters, or tends to alter, the motion of a body, or that of its invisible particles.

Energy is the capacity or power of doing work. There are two kinds or forms of energy, viz., the energy which a body possesses in virtue of its motion, called *Kinetic Energy*, and *Potential Energy*, or energy of position.

Momentum is quantity of motion. It is measured by multiplying the mass of the moving body by its velocity.

Stress is the word used to denote the whole phenomena of the action, or the mutual action, between two portions of matter.

6. What are the facts which prove that the earth revolves round the sun, and not the sun round the earth?

(*a*) The Aberration of light: Owing to the motion of the earth in its orbit, combined with the velocity of light, stars are always seen twenty seconds of arc in advance of their true position. The result of this is that in a year the stars describe ellipses in the heavens representing the earth's orbit in miniature. The major axis of each apparent ellipse is 40″, but the minor axis is least for stars on the ecliptic, and greatest for stars near the pole of the ecliptic, when it becomes equal to the major axis.

(*b*) The Annual Parallax of fixed Stars: Some of the stars are seen in a slightly different direction when viewed at intervals of six months. This is because they are observed from two opposite points on the earth's orbit.

(*c*) Newton's Proof: It can be shown mathematically that the earth must move around the sun, and not the sun around the earth, in consequence of its smaller mass. In fact, the two bodies move around their common centre of gravity.

7. How has the shape of the earth's orbit been determined?

By measuring the sun's angular diameter throughout the year. The sun would always appear to have the same diameter if the earth moved around it in a circular path, but daily measurements show that it increases from July to January, and then decreases from January to July every year. By plotting down the series of measures, it has been found that the shape of the earth's orbit is that of an ellipse or oval, the sun occupying one of the two foci.

8. What is sidereal and what is mean time?

Sidereal Time is time reckoned or measured by the stars. The interval that elapses between two successive transits of a star—a sidereal day—is divided into twenty-four hours. The starting point of a sidereal day, and the point from which sidereal time is counted, is the 'First point of Aries.' When this crosses the meridian of a place, the sidereal time is 0 hours 0 mins. 0 secs. The number of hours, minutes, and seconds that have elapsed since the transit of the First Point of Aries is the sidereal time at the moment of observation.

Mean Time is time kept by an imaginary sun moving uniformly along the equator at the same average rate as the real sun in the ecliptic.

The following Apparatus, &c., is considered by the Department of Science and Art to be indispensable for the efficient teaching of Physiography. The articles can be obtained, at the prices quoted below, from J. J. Griffin & Sons, Garrick Street, London, W.C.

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Electrical Glass Tube	0	2	6	0	2	6
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Stick of Shellac	0	2	0	0	2	0
,, Sulphur	0	2	0	0	2	0
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INDEX.